Supernova and Star Formation Rates

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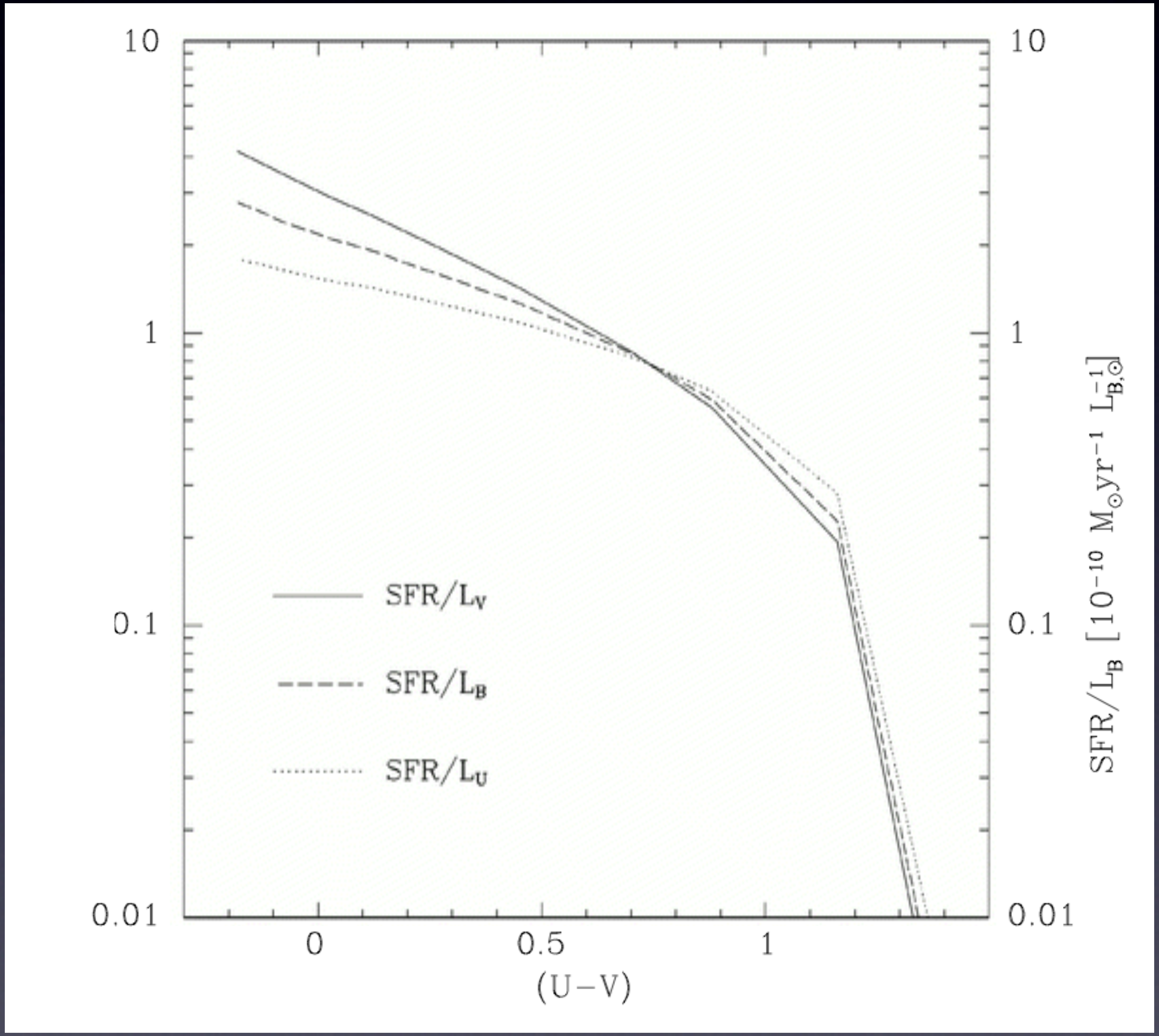
SN vs. SF rates

Kennicutt 1998
SFR vs. galaxy color from evolutionary synthesis model



Cappellaro etal 1999   136 SNe photographic & visual

SN vs. SF rates

$$r_{cc} = K_c \times SFR$$

$$K_{cc} = \frac{\int_{m_L^{cc}}^{m_U^{cc}} \varphi(m)\mathrm{d}m}{\int_{m_L}^{m_U} m\varphi(m)\mathrm{d}m}$$

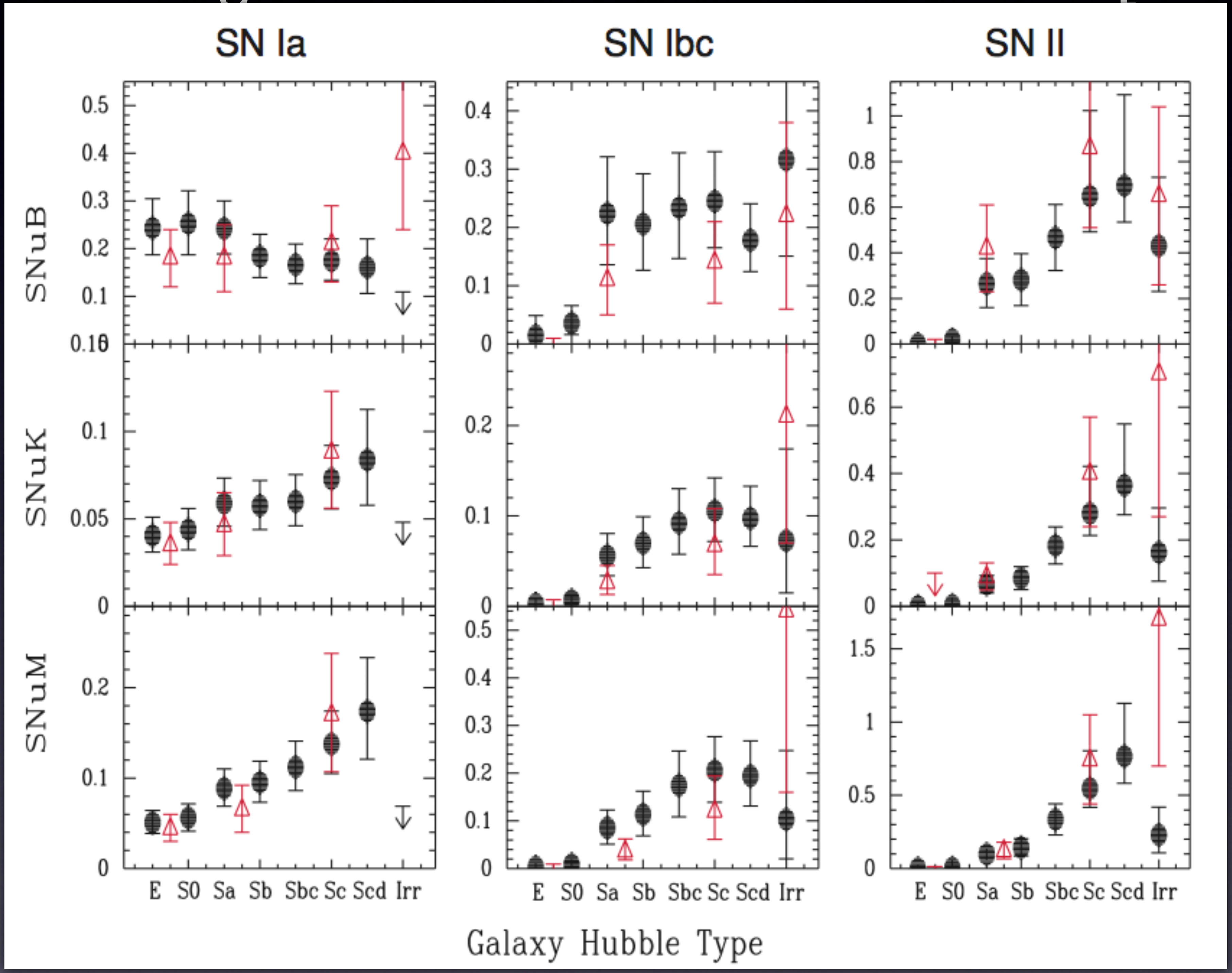
$$\varphi(m) = \mathrm{IMF}$$

progenitor scenario

$$8 - \boxed{10 < m < 40} - 100\, M_\odot$$

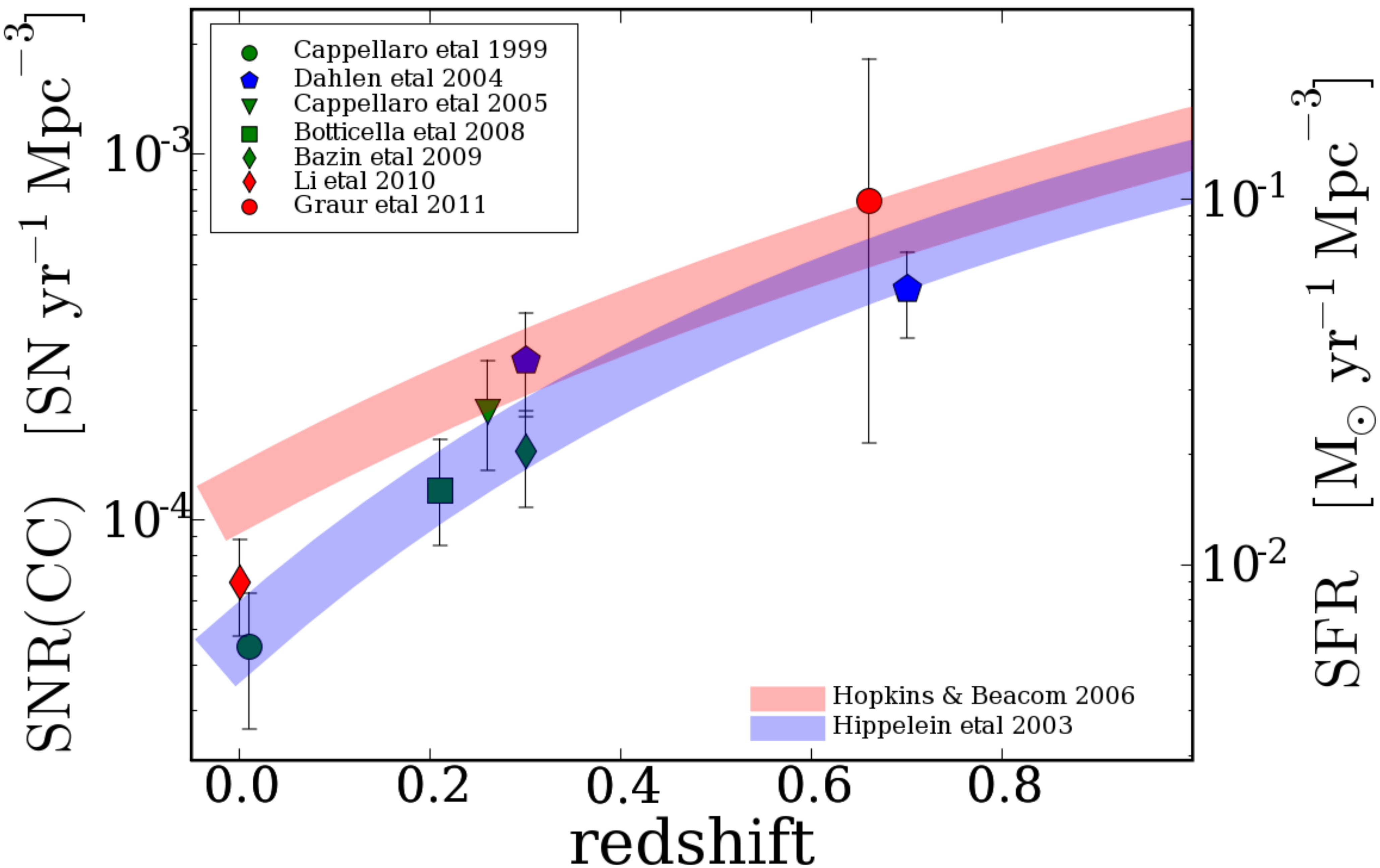
SN rates in the local Universe

Weidong Li et al. 2011   726 SNe CCD   [LOSS]

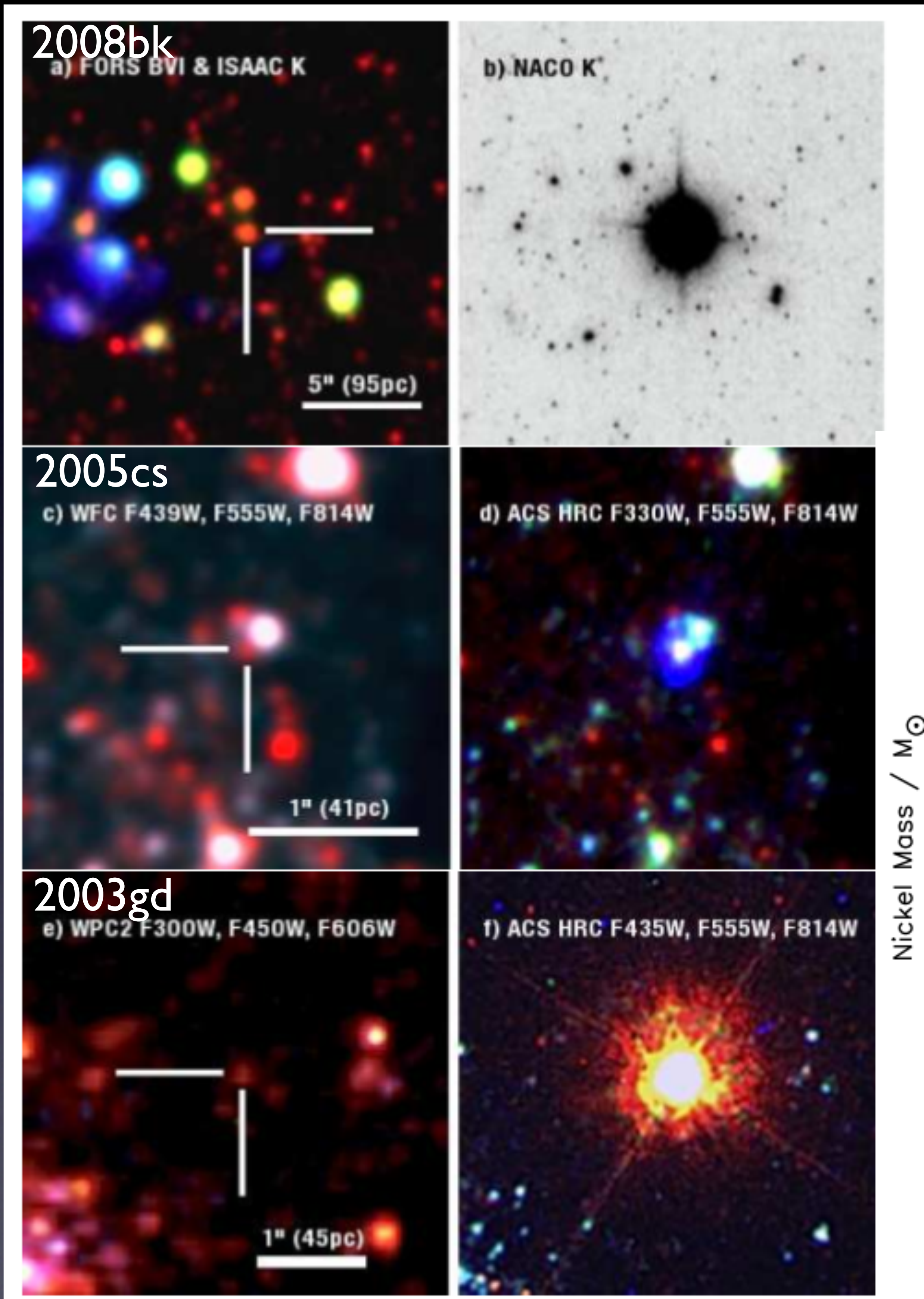


SN vs. SF rates

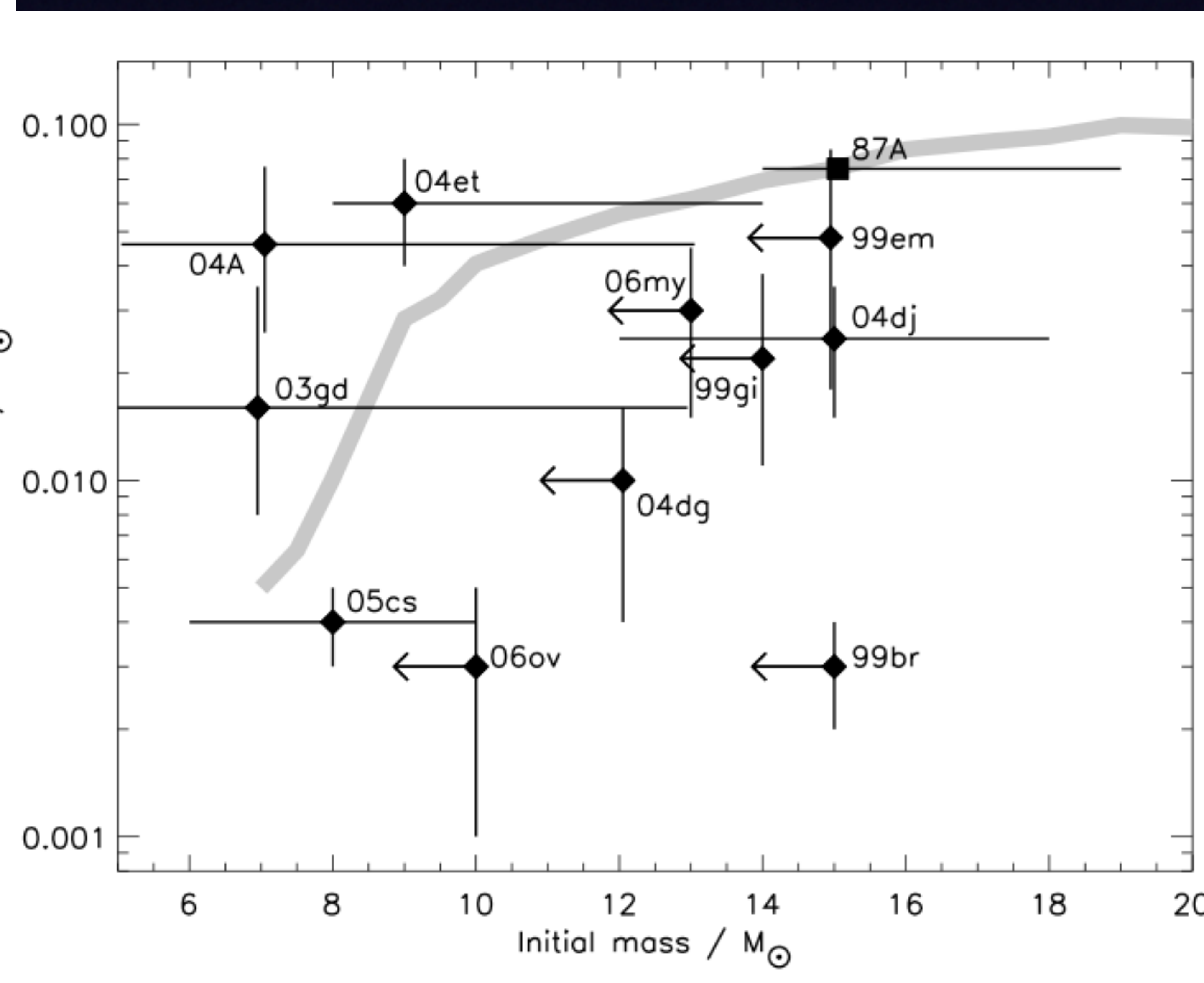
10 < Mcc < 50 M☉



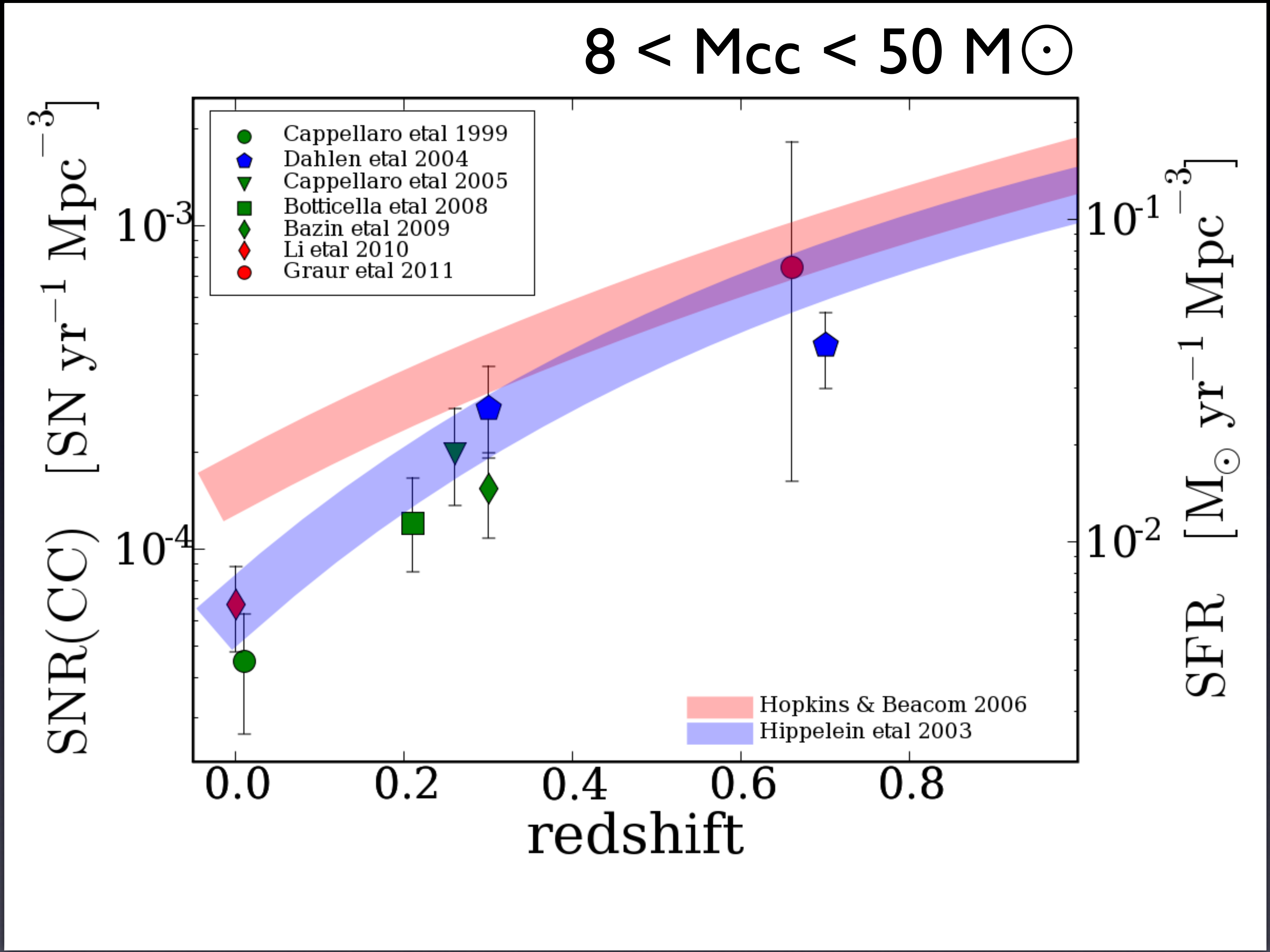
Core collapse progenitor mass



Smartt etal 2009



SN vs. SF rates



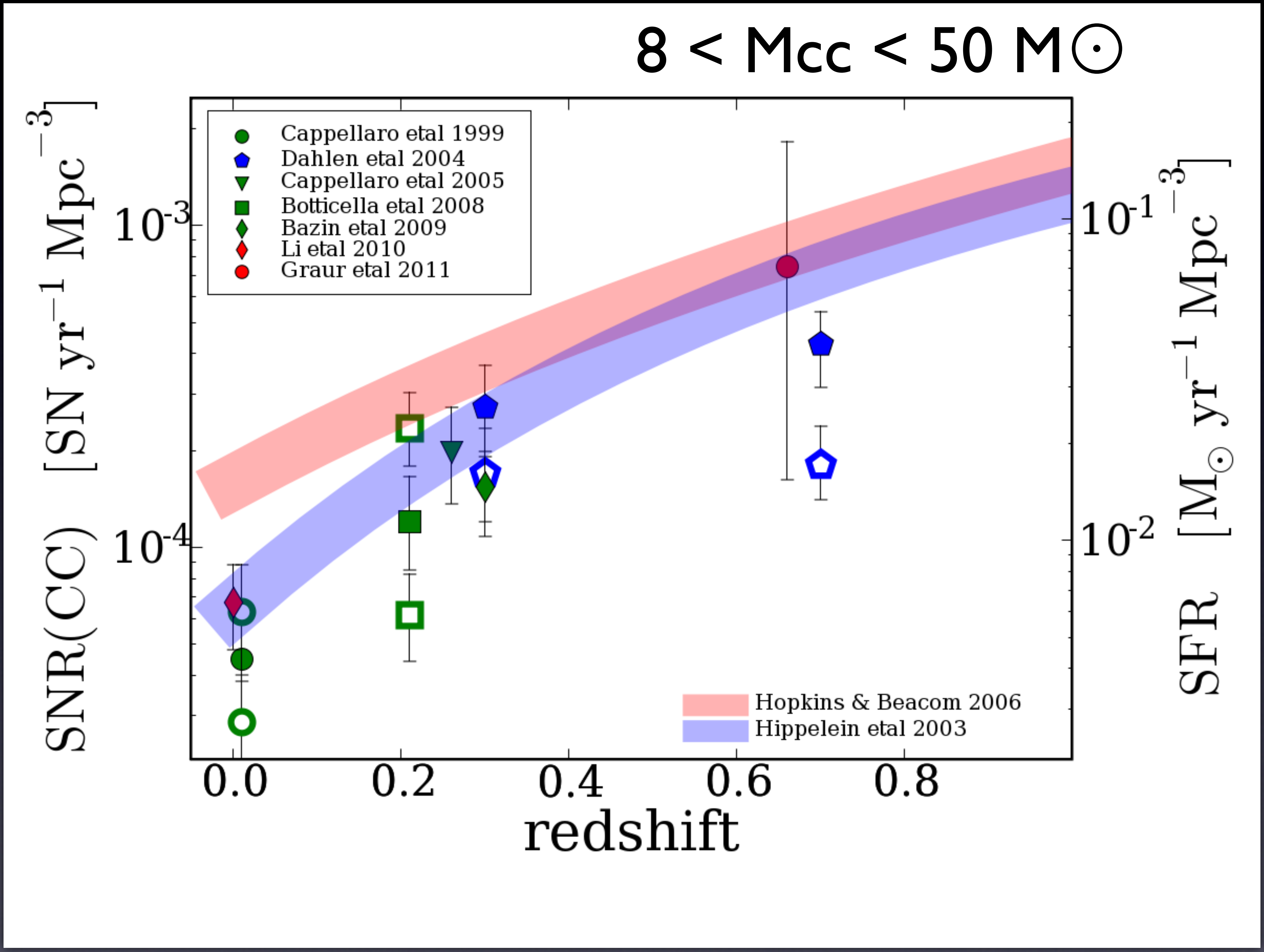
The Cosmic Core-collapse Supernova Rate Does Not Match the Massive-star Formation Rate

Horiuchi etal 2011 (ApJ 738,154)

We identify a "supernova rate problem:" the measured cosmic core-collapse supernova rate is a factor of ~2 smaller (with significance ~2σ) than that predicted from the measured cosmic massive-star formation rate

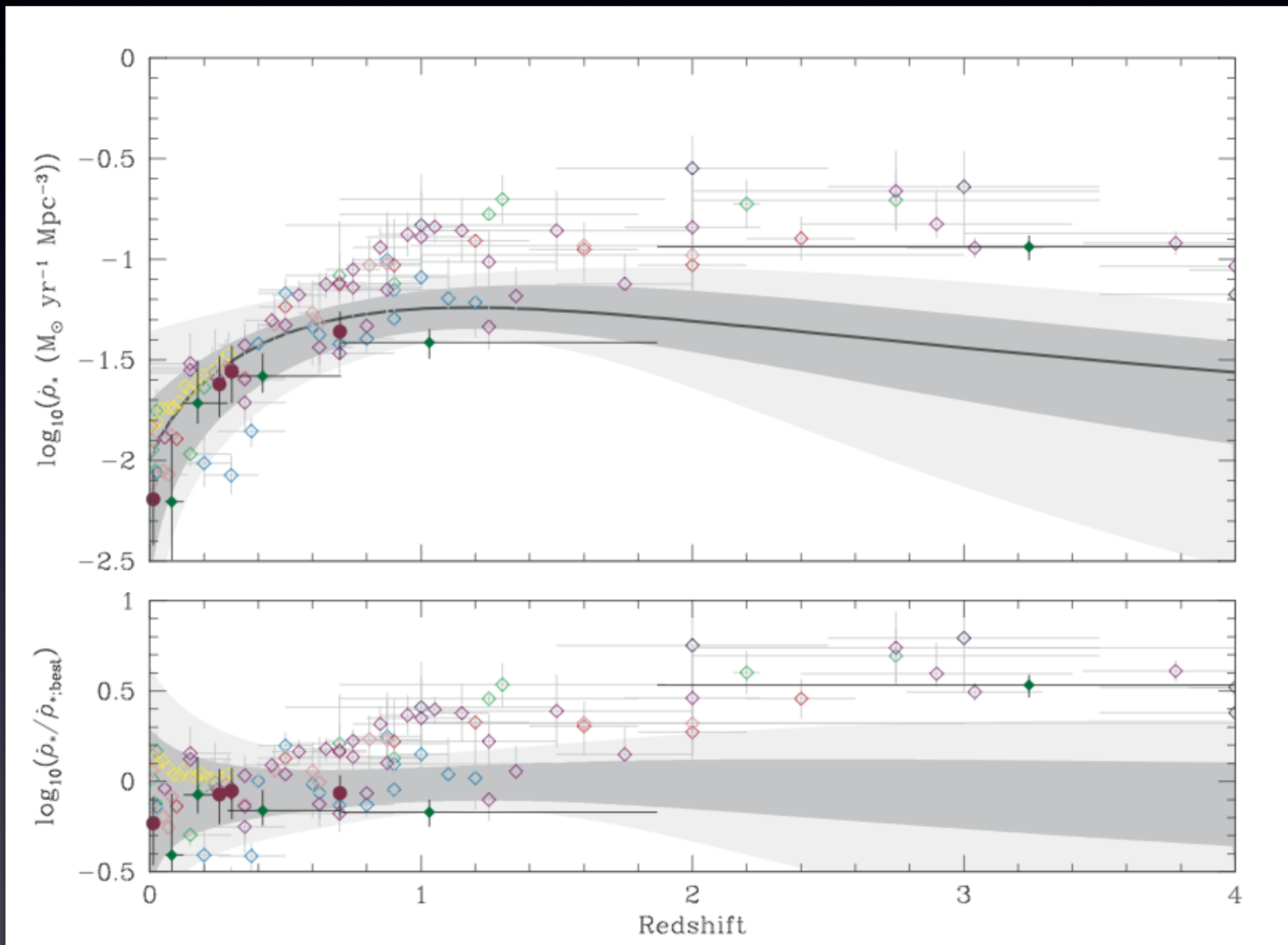
If possible supernova impostors are included, then dim supernovae are common enough by fraction to solve the supernova rate problem. If they are not included, then the rate of dark core collapses is likely substantial.

SN vs. SF rates

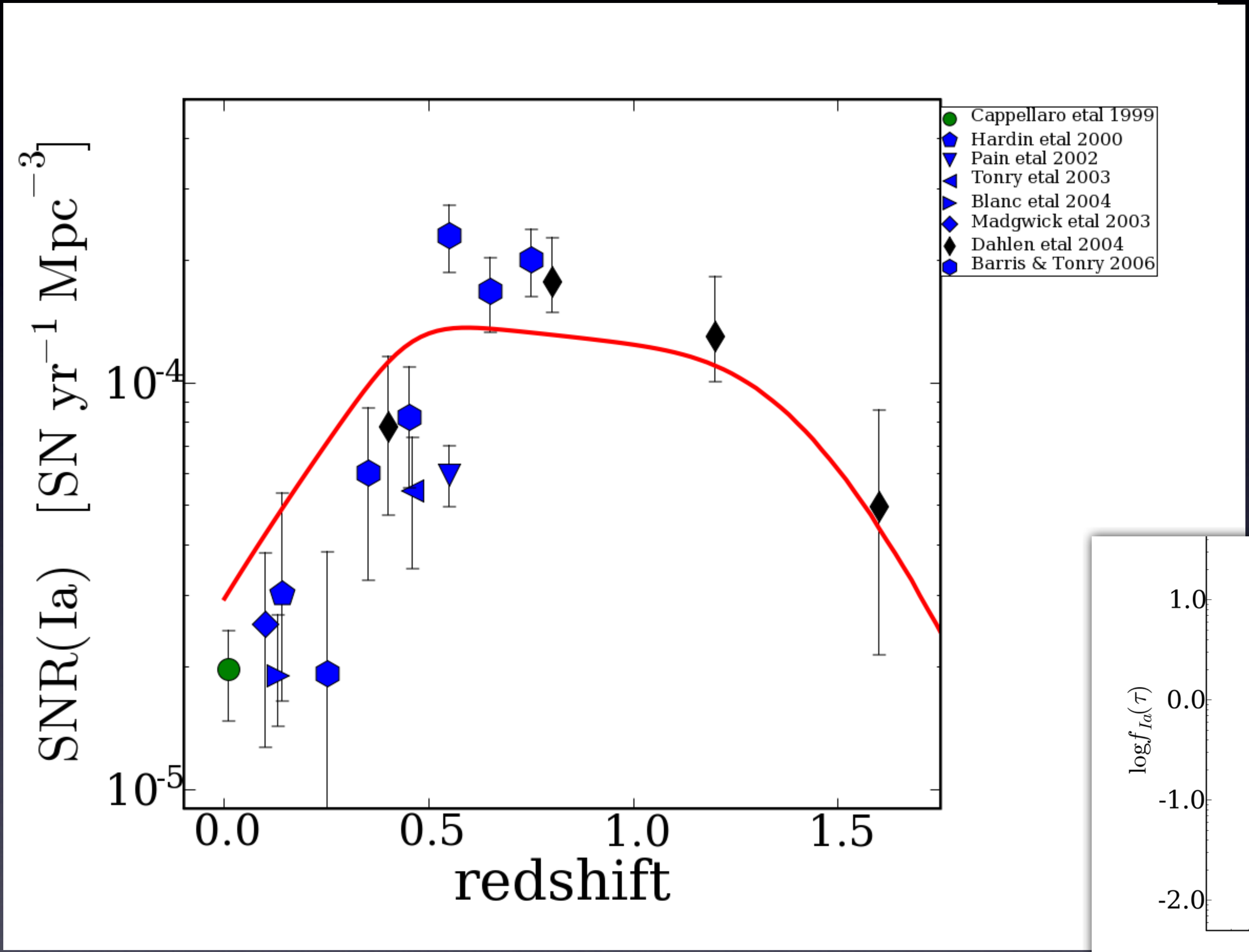


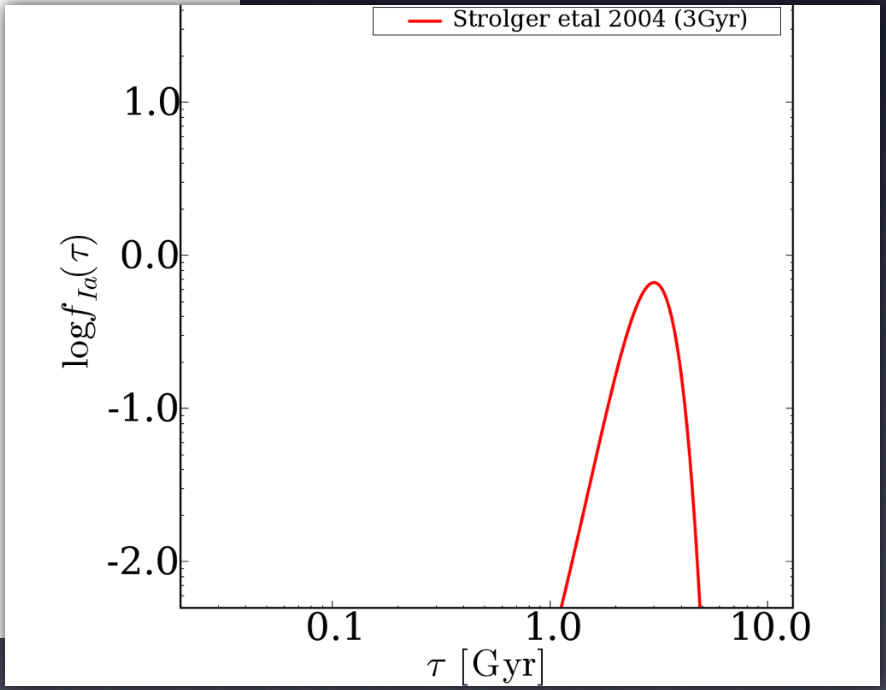
Stellar mass density and SFH

Wilkins etal. 2008



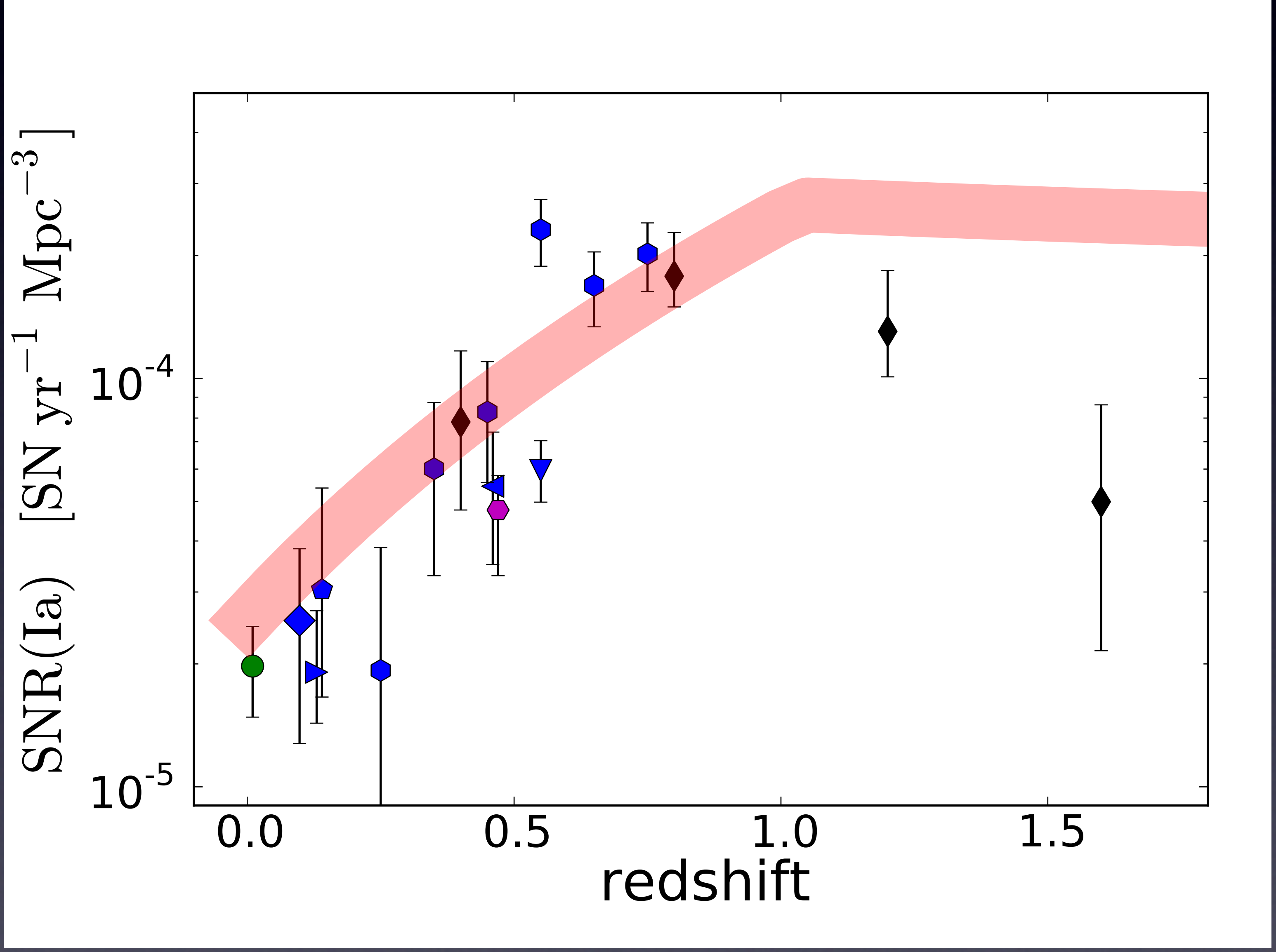
SNIa rate with redshift



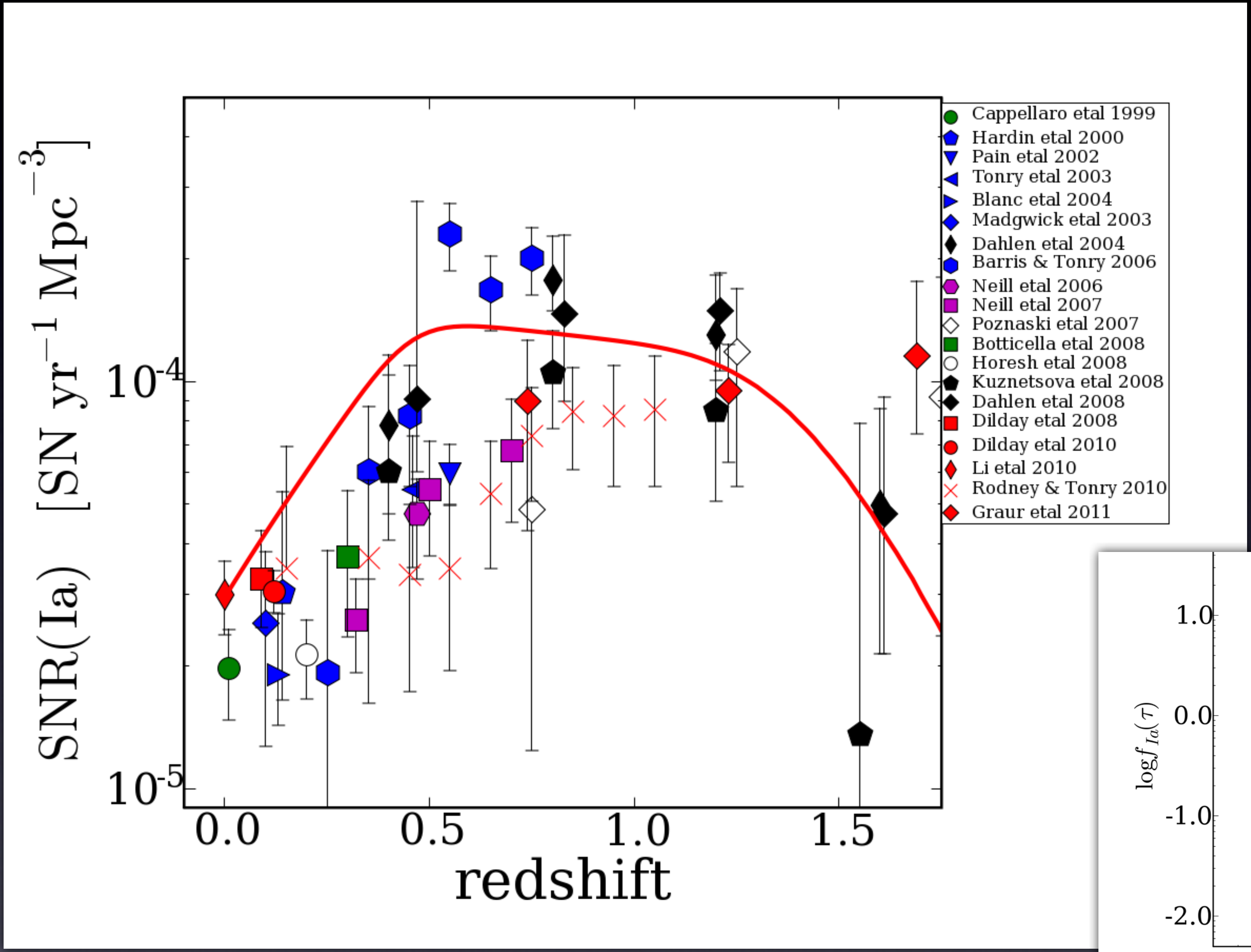


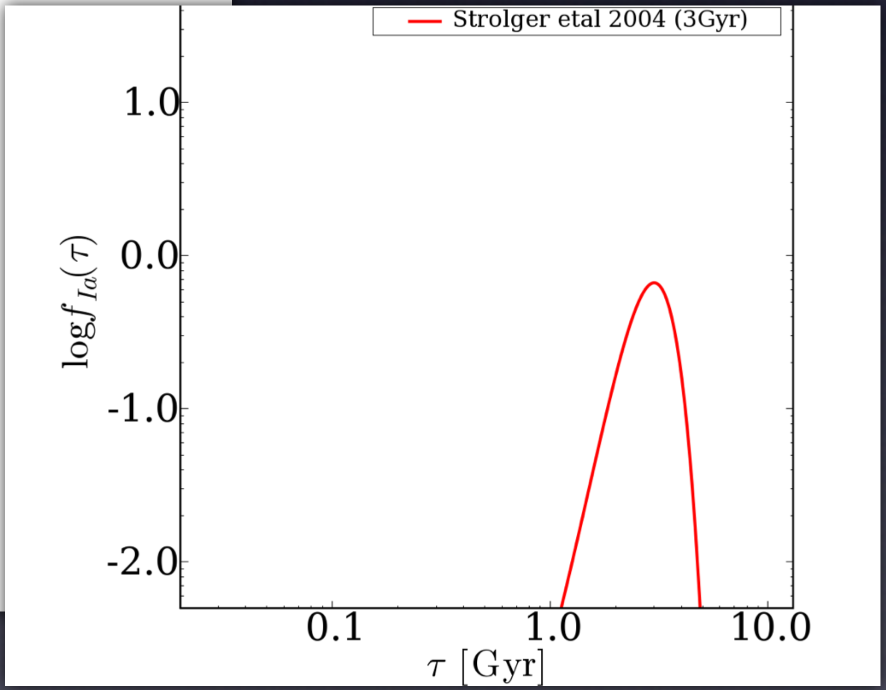
SFH and SN rate

similar rapid decline ??

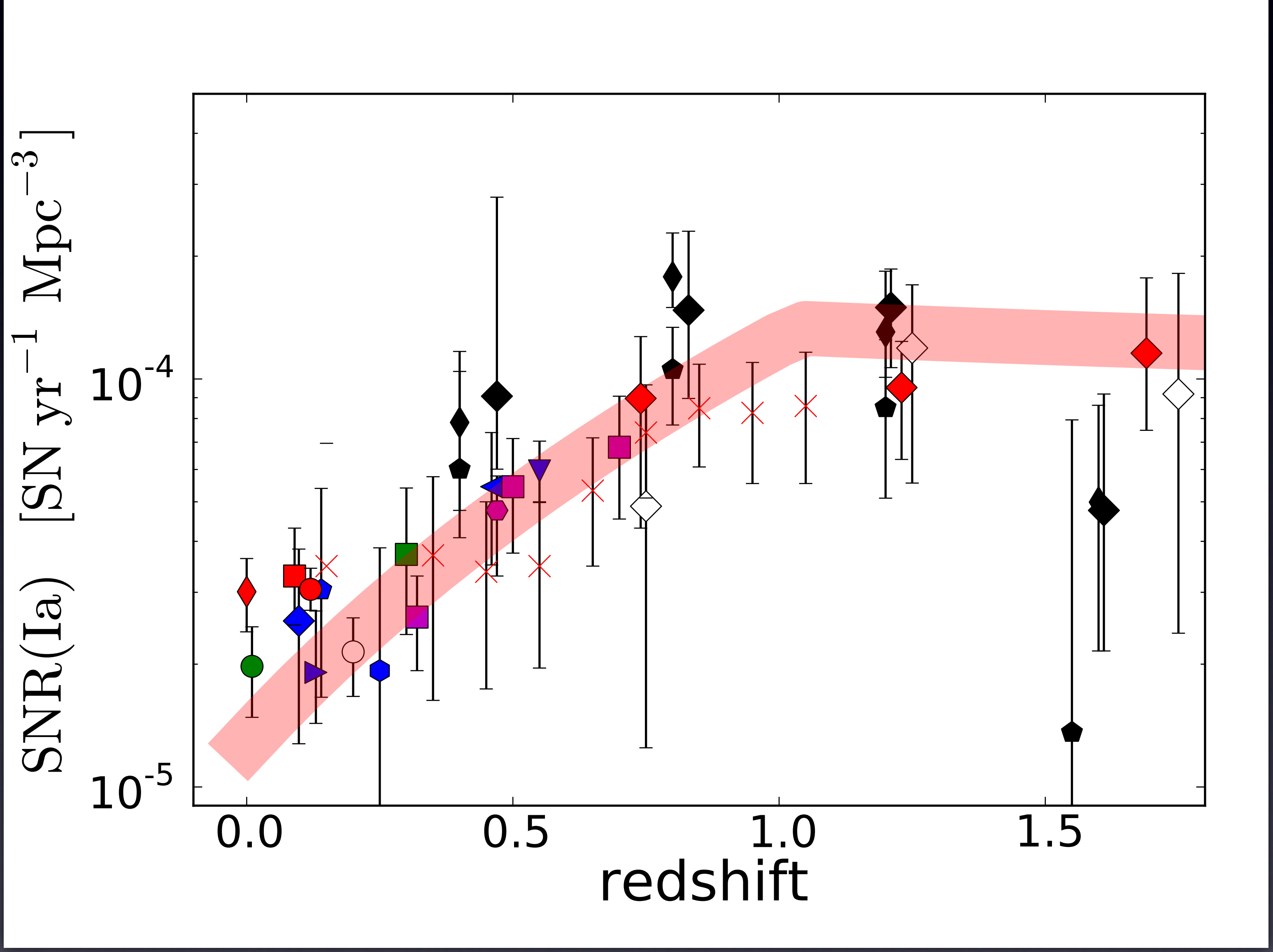


SNIa rate with redshift



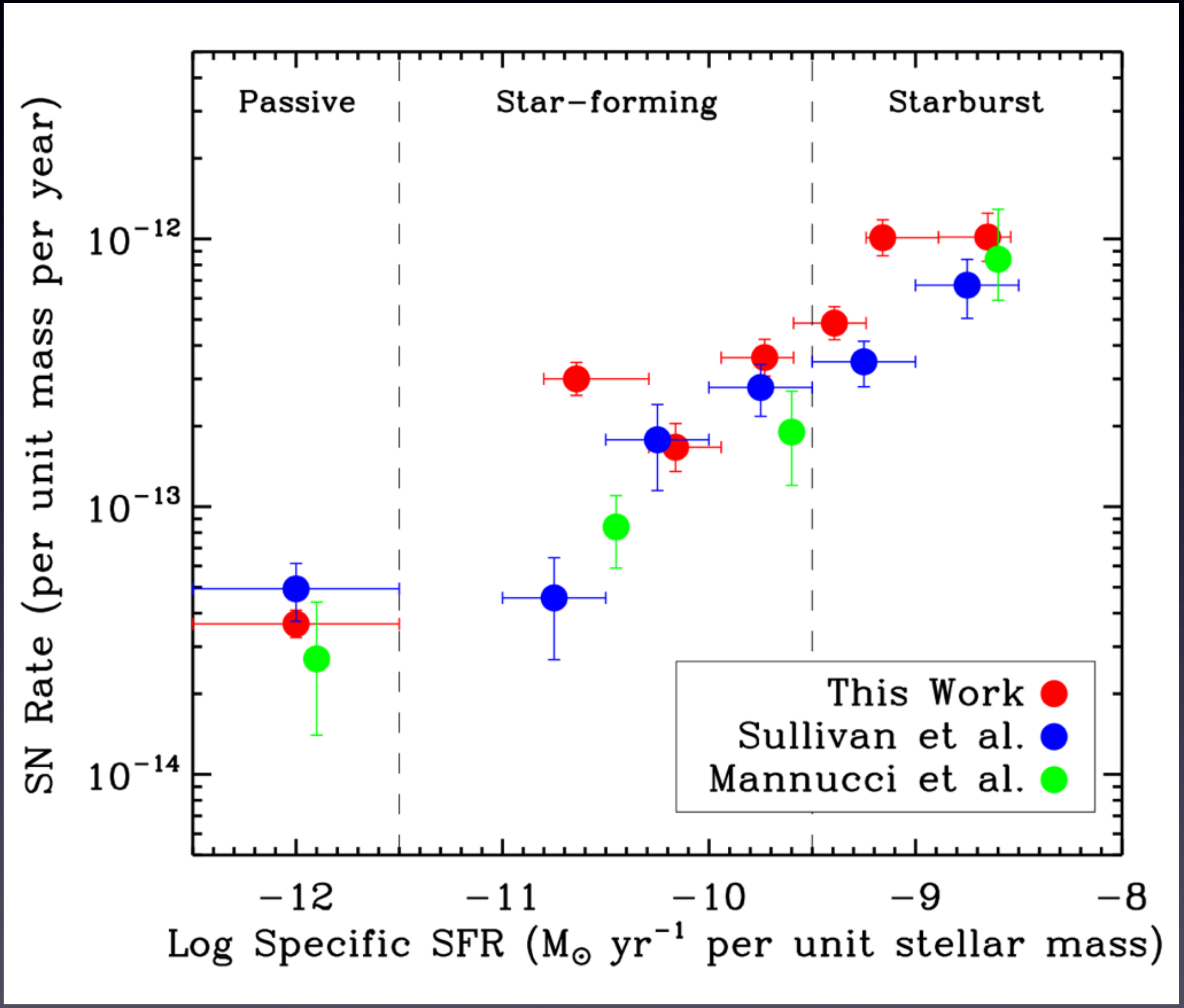


SFH and SN rate
similar rapid decline ??



SNIa rate & SFR

Smith et al. 2011 “The SDSS-II ...



... rate soon after starburst 10x than in passive galaxies

SNIa realization fraction

the fraction of stars in the selected 3-8M mass range which ends up as SN Ia are:

5 %

Blanc & Greggio 2008

15 %

Maoz (2008)

"…. nearly every intermediate-mass close binary ends up as a SN Ia."

Maoz & Mannucci 2011

Source	$N_{\rm SN}/M_*$ $[10^{-3}\ {\rm M}_\odot{}^{-1}]$	Ref.
Cluster Fe content	> 3.4	a
Magellanic SN remnants	> 2.7	b
Cluster rates, $\Psi \propto t^{-1}$	2.5 ± 0.4	a,c
Cluster rates, $\Psi \propto t^{-0.9}$	2.0 ± 0.2	a,c
LOSS SDSS-I galaxies	2.0 ± 0.6	d
SDSS-II galaxies	2.1 ± 0.3	e
Volumetric rates to $z = 2$	1.0 ± 0.5	f

[a] Maoz et al. (2010)
[b] Maoz & Badenes (2010)
[c] This work
[d] Maoz et al. (2011)
[e] Maoz & Mannucci, in prep.
[f] Graur et al. (2011)

3-10%

Ia rates versus redshift suggest $N_{\rm SN}/M_* \approx 1$. This could be an indication that most SFH estimates have been overestimated, perhaps due to over-correction for extinction, by 50%, or even a factor of 2 (see discussion of this point in Graur et al. 2011). It is hard to be-

Test local individual galaxies

A comparison between star formation rate diagnostics and rate of core collapse supernovae within 11 Mpc

Botticella et al 2012 A&A 537 ,132

HAWK-I Infrared SN search in a sample of starburst galaxies

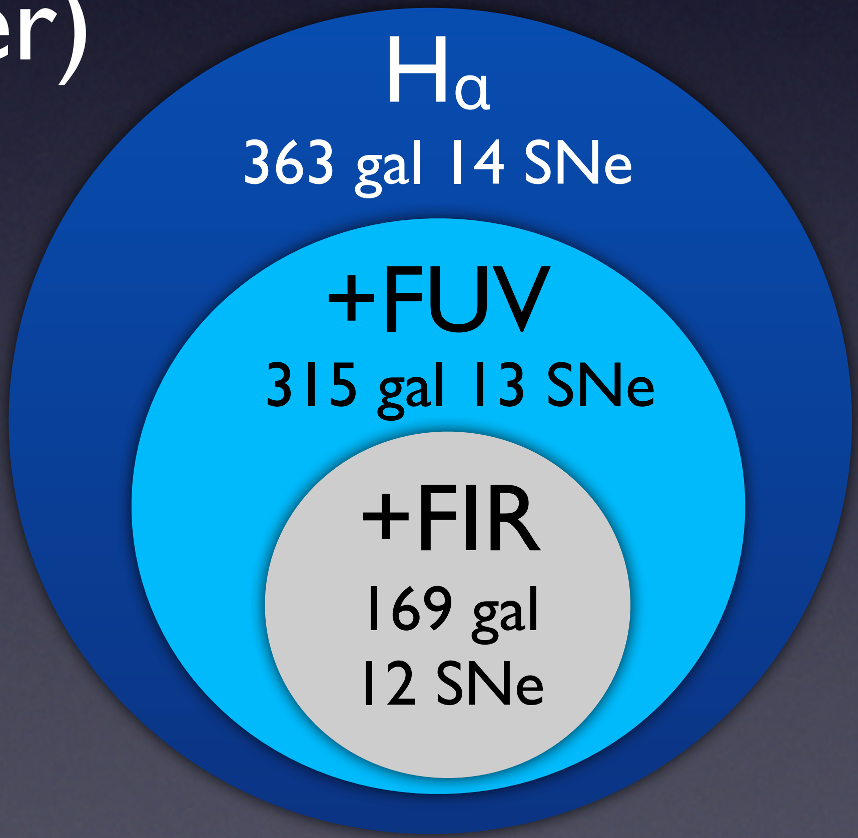
Miluzio june 2012 PhD Thesis

A comparison between star formation rate diagnostics and rate of core collapse supernovae within 11 Mpc

Samples:

- The 11 Mpc Hα and Ultraviolet Galaxy Survey (11HUGS) *Kennicutt etal 2008, Lee etal 2011*
Hα (BOK), FUV (Galex), FIR (Spitzer)

- The list of SNe discovered in 11HUGS in this century.
Asiago SN Catalog



Botticella et al 2012 A&A 537 ,132

Integrated Hα luminosity

$$SFR\,(M_\odot\,yr^{-1}) = 7.9 \times 10^{-42} L_{H_\alpha}\,(erg\,s^{-1})$$

Kennicutt 1998,2009

FUV luminosity from GALEX (Lee etal 2011)

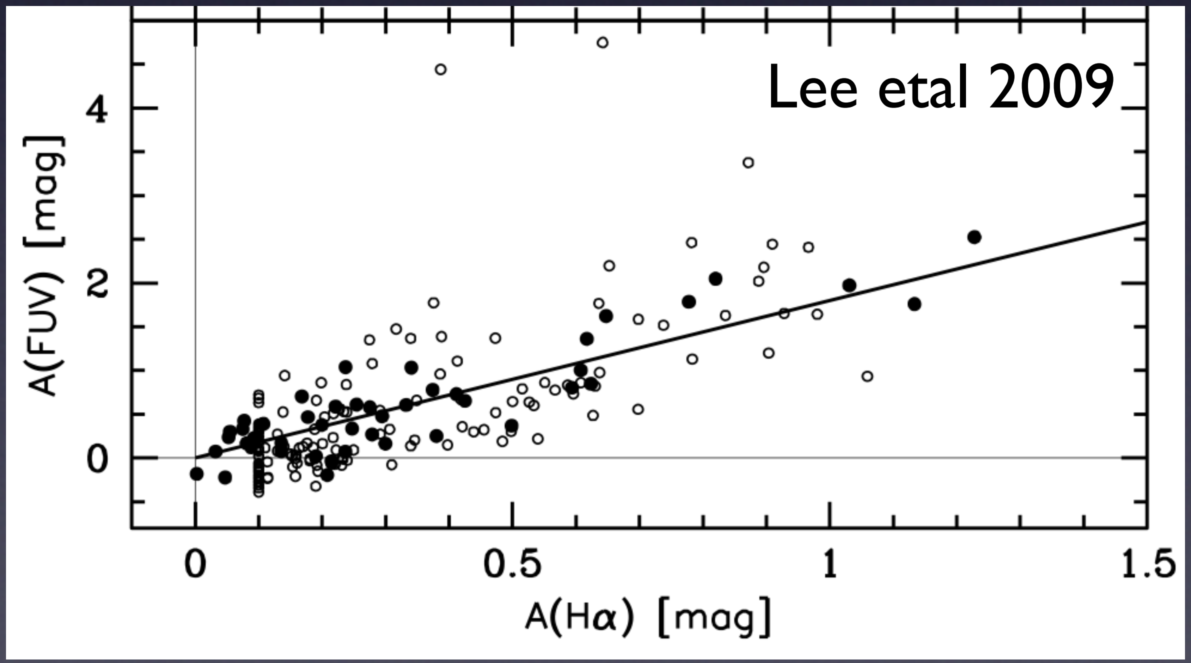
$$SFR\,(M_\odot\,yr^{-1}) = 1.4 \times 10^{-28} L_{H_\alpha}\,(erg\,s^{-1}\,Hz^{-1})$$

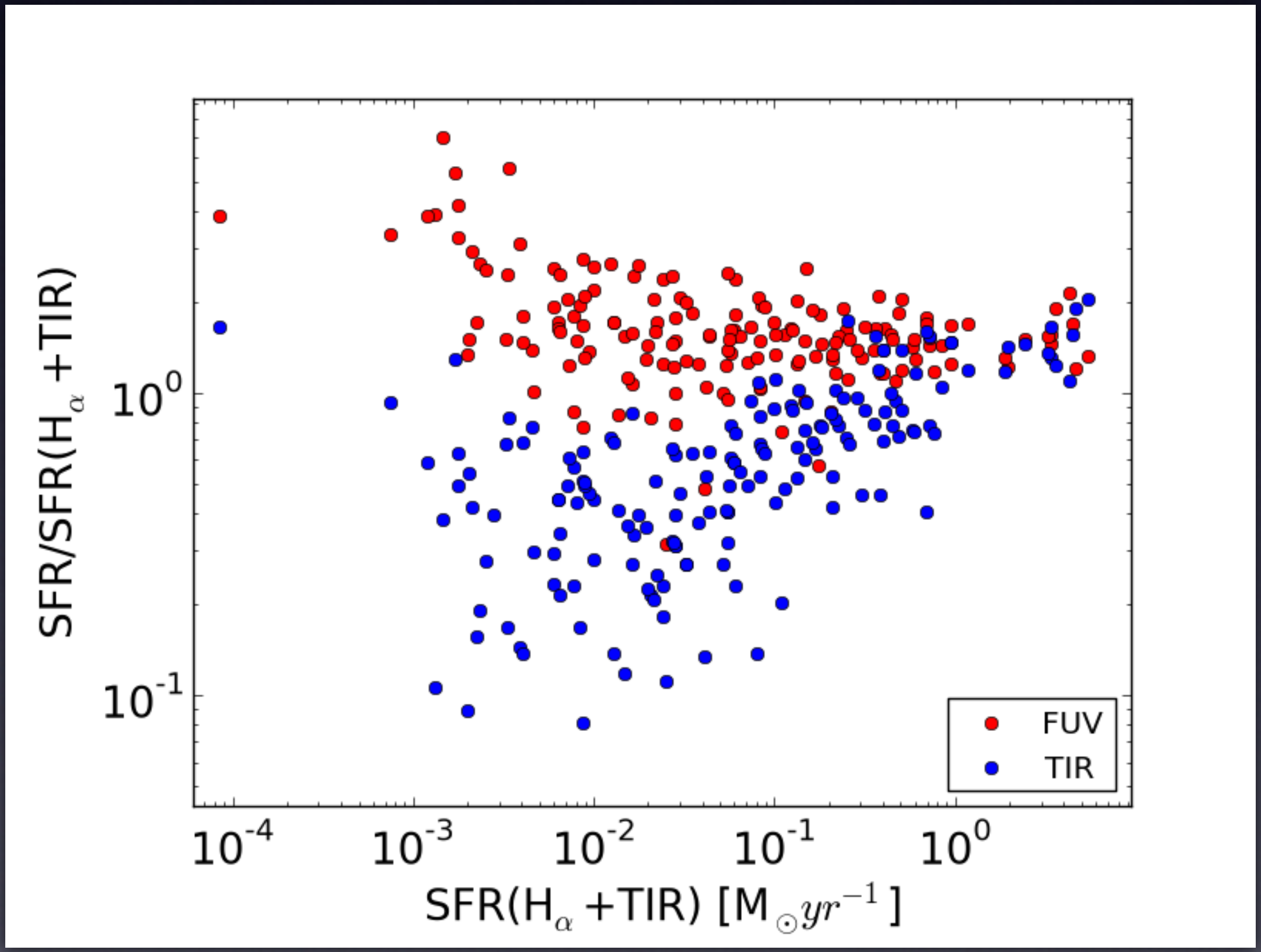
Total IR luminosity

$$SFR(M_\odot\,yr^{-1}) = 4.5 \times 10^{-44}\,L_{TIR}\,(erg\,s^{-1})$$ *starburst*

Hα + IR luminosity

$$SFR(M_\odot\,yr^{-1}) = 7.9 \times 10^{-42}(L_{H_\alpha} + 0.0024 L_{TIR})\,(erg\,s^{-1})$$





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2000. SNe in HUGS

SN	Type	Mag disc.	Mag max.	Phase	Ref.	Gal.	T	Host M_B	$SFR_{H\alpha}$	SFR_{UV}	$B-K$	M	$sSFR$	$EW(H\alpha)$
2002ap	Ic	14.5 (V)	12.39 (V)	–9	1	NGC 628	5	−19.58	1.3	2	2.3	2	11	35
2002bu	IIn	15.5	14.77 (R)	–5	2, 3	NGC 4242	8	−18.18	0.1	0.17	1.9	0.2	9	18
2002hh	IIP	16.5	15.53 (R)	–4	4, 5	NGC 6946	6	−20.79	5.7	9.1	2	3.6	26	33
2003gd	IIP	13.2	13.63 (R)	+90	6, 7	NGC 628	5	−19.58	1.3	2	2.3	2	11	35
2004am	IIP	17.0	~16 (R)	+90	8, 9	NGC 3034	7	−18.84	1.9	5.6	3.6	6.4	9	64
2004dj	IIP	11.2	11.55 (R)	+21	10, 11	NGC 2403	6	−18.78	0.8	1.0	2.2	0.6	17	50
2004et	IIP	12.8	12.2 (R)	–18	12, 13	NGC 6946	6	−20.79	5.7	9.1	2	3.6	26	33
2005af	IIP	12.8	12.8 (R)	+30	14	NGC 4945	6	−19.26	0.9	–	–	–	–	17
2005at	Ic	14.3	14.3	0	15	NGC 6744	4	−20.94	3.3	12	–	–	–	15
2005cs	IIP	16.3 (V)	14.50 (V)	–2	16, 17	NGC 5194	4	−20.63	4.5	7.6	2.6	8.5	9	28
2007gr	Ic	13.8	12.76	–13	18, 19	NGC 1058	5	−18.24	0.3	0.5	2	0.3	14	29
2008S	...	16.7 (R)	16.26 (R)	–11	20, 21	NGC 6946	6	−20.79	5.7	9.1	2	3.6	26	33
2008ax	IIb	16.1	13.38 (r)	–23	22, 23	NGC 4490	7	−19.37	1.9	2.5	2.3	1.3	18	66
2008bk	IIP	12.6	12.5		24, 25	NGC 7793	7	−18.41	0.5	0.7	2.4	0.5	13	40
2008OT	...	14.3	14.3	0	26	NGC 300	7	−17.84	0.2	0.3	–	–	–	24
2009hd	IIP	17.2	16 (R)		27	NGC 3627	3	−20.44	2.6	4.9	3	12	4	19

Botticella et al 2012 A&A 537 ,132

SFR(UV) 50% larger than SFR(H$_\alpha$+TIR)
Likely due to (incorrect) extinction correction

Table 3. Estimated minimum mass in different galaxy samples and for different SN samples.

Sample	SFR ($M_\odot$ yr^{-1})	$m^{\rm CC}_{1,13}$ ($M_\odot$)	$m^{\rm CC}_{1,13+\rm old}$ ($M_\odot$)	$m^{\rm CC}_{1,13+\rm prior}$ ($M_\odot$)
A	$SFR_{\rm H\alpha} = 87 \pm 4$	6 ± 1	5.8 ± 0.9	6.2 ± 0.8
B	$SFR_{\rm UV} = 123 \pm 8$	8 ± 2	8.2 ± 0.9	8.7 ± 1.2
C	$SFR_{\rm H\alpha} = 58 \pm 3$	5 ± 1	4.0 ± 0.5	6.0 ± 0.6
	$SFR_{\rm H\alpha+TIR} = 62 \pm 3$	5 ± 1	4.5 ± 0.4	6.0 ± 0.8
	$SFR_{\rm UV} = 94 \pm 6$	7 ± 2	6.2 ± 0.7	7.5 ± 1.1

Lower limit for core collapse progenitor 6-8 $M_\odot$

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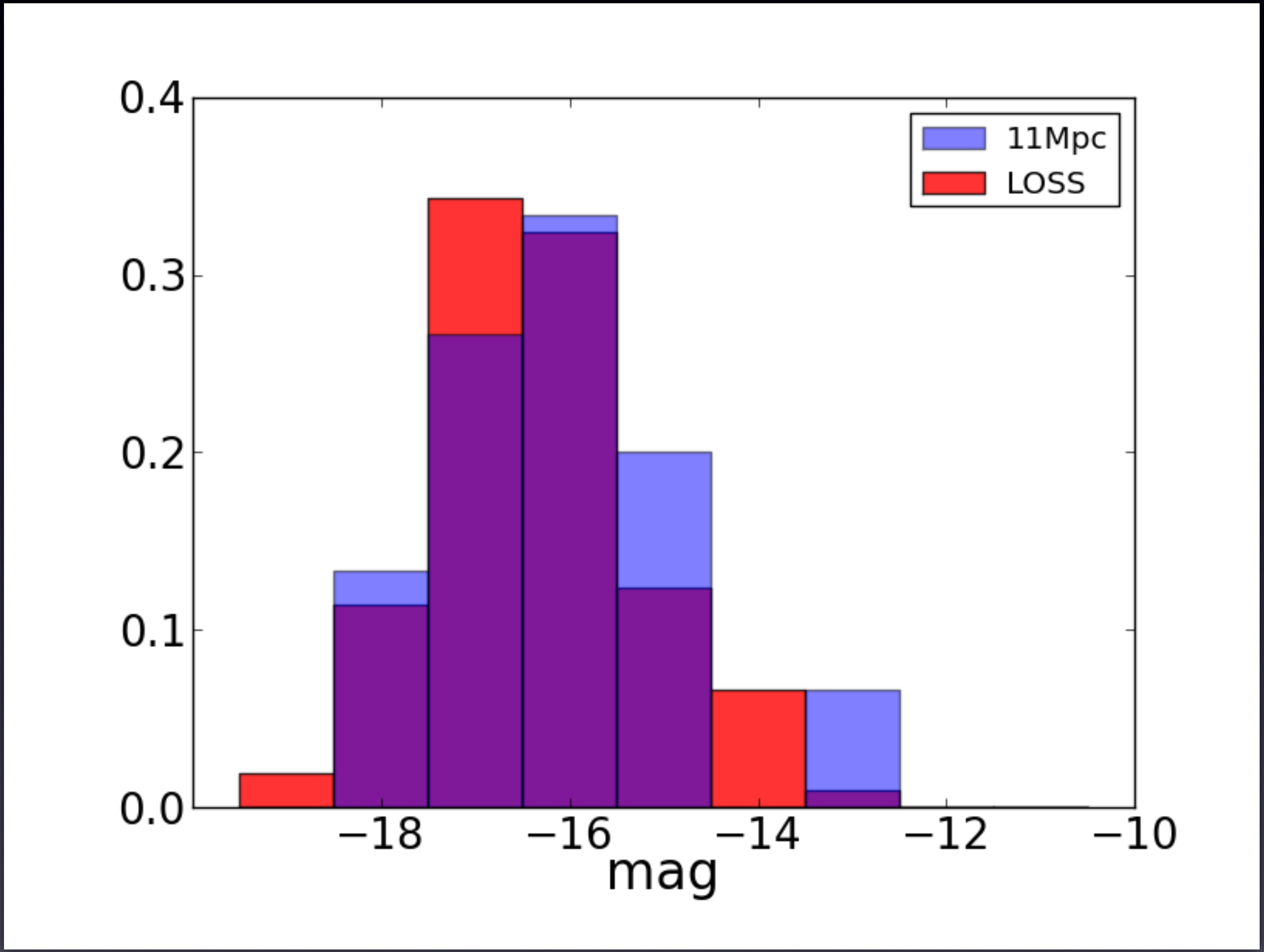
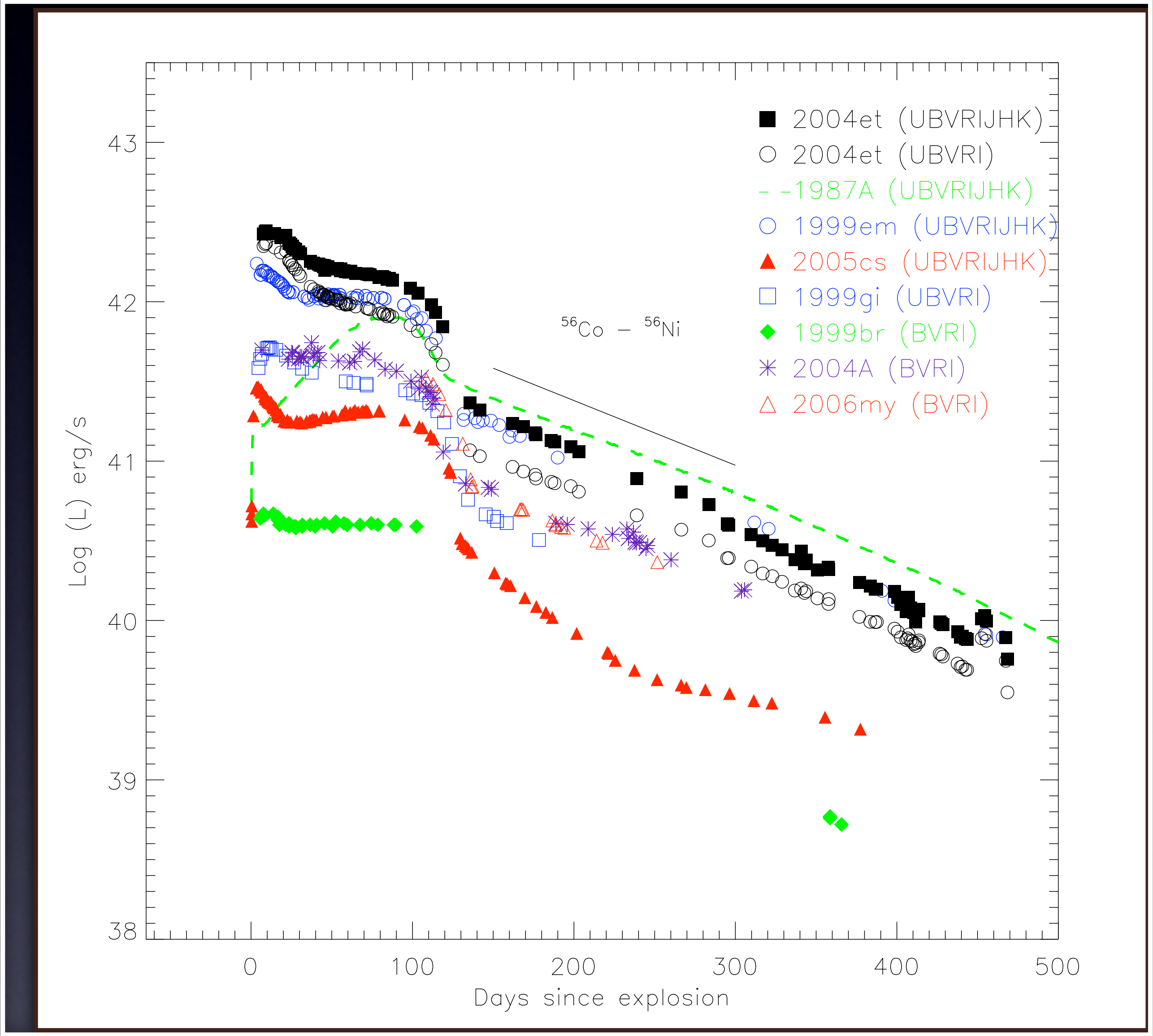
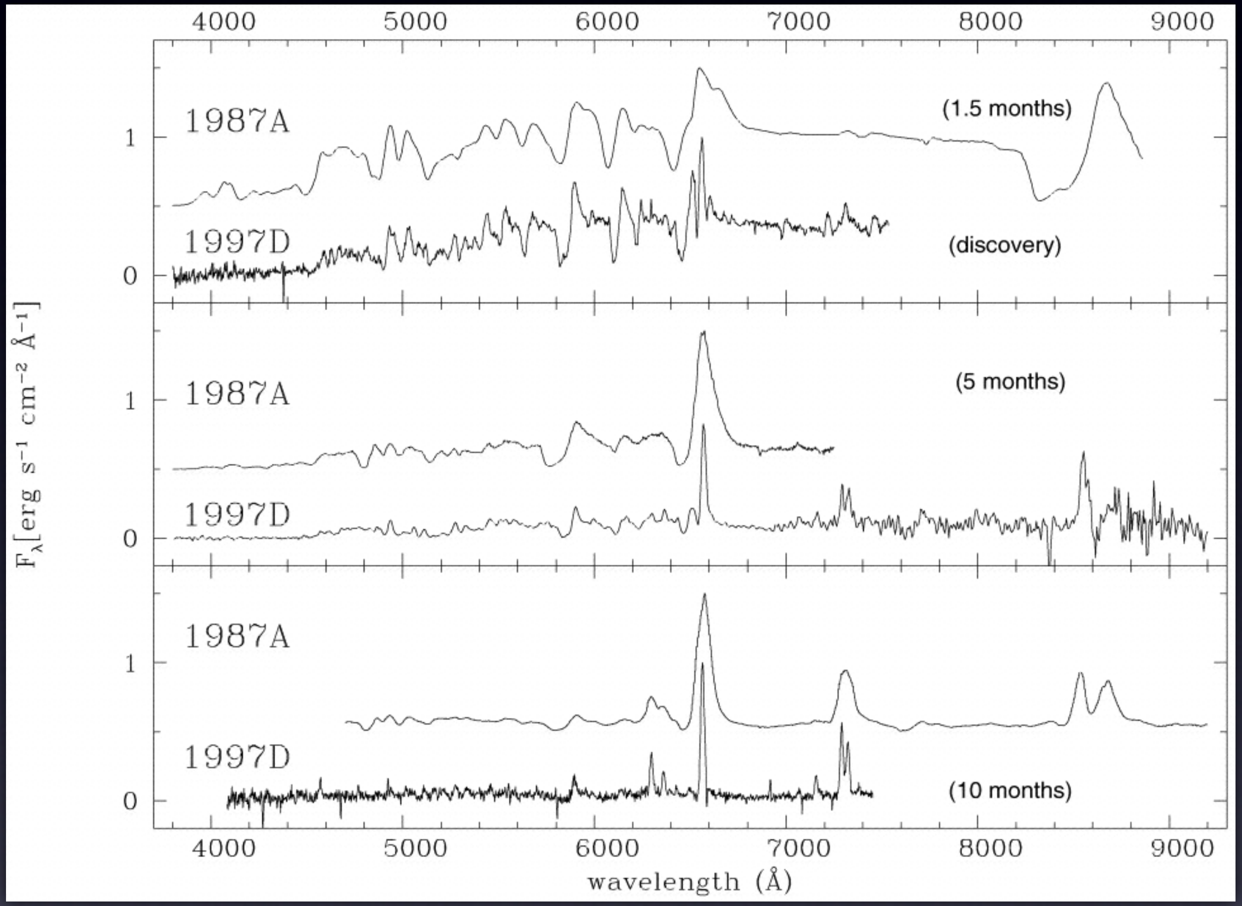
Core Collapse SN luminosity function



Faint core collapse SNe

Small Ni mass - Low energy explosion





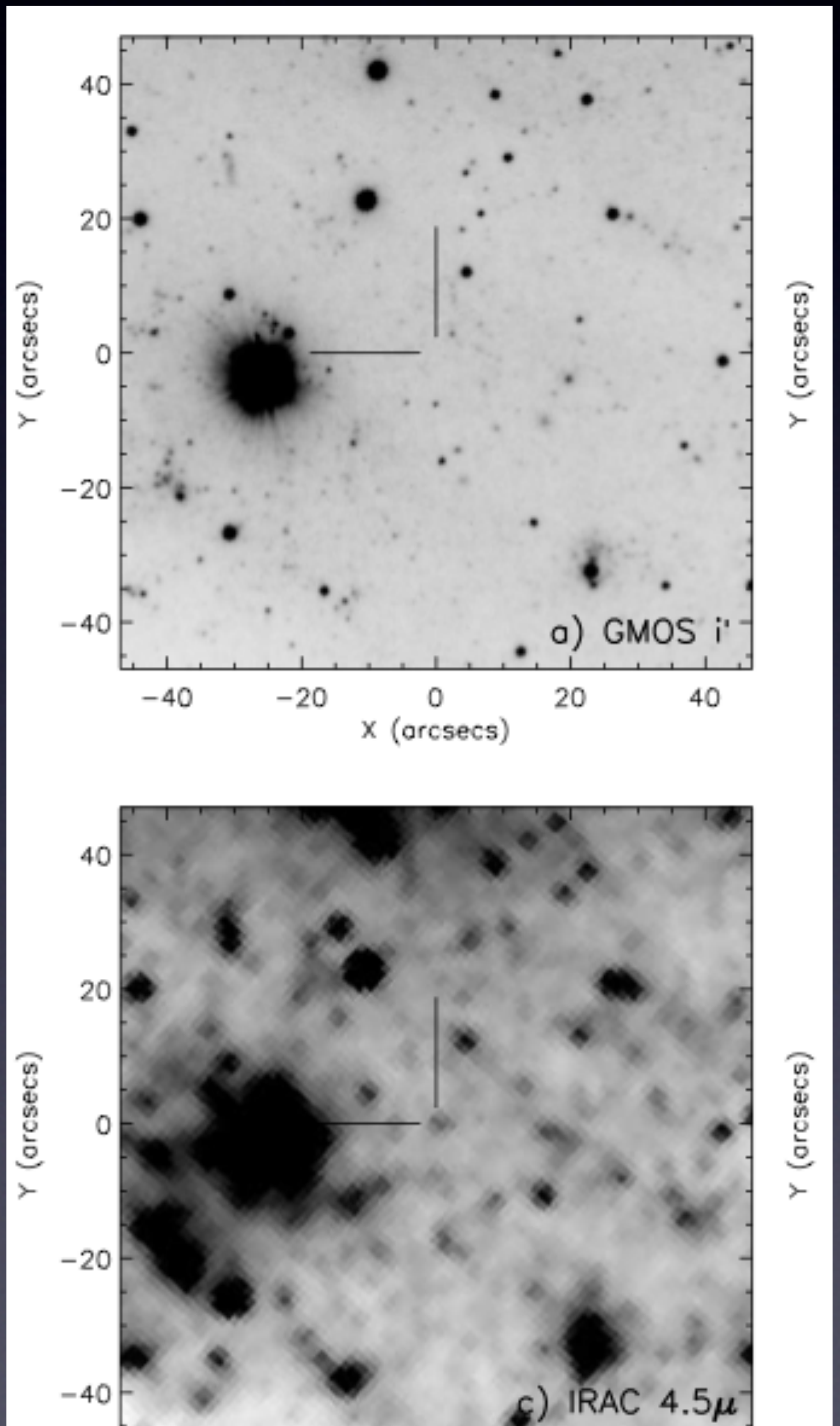
$0.1 > M_{Ni} > 0.002 M_\odot$

progenitor scenario:

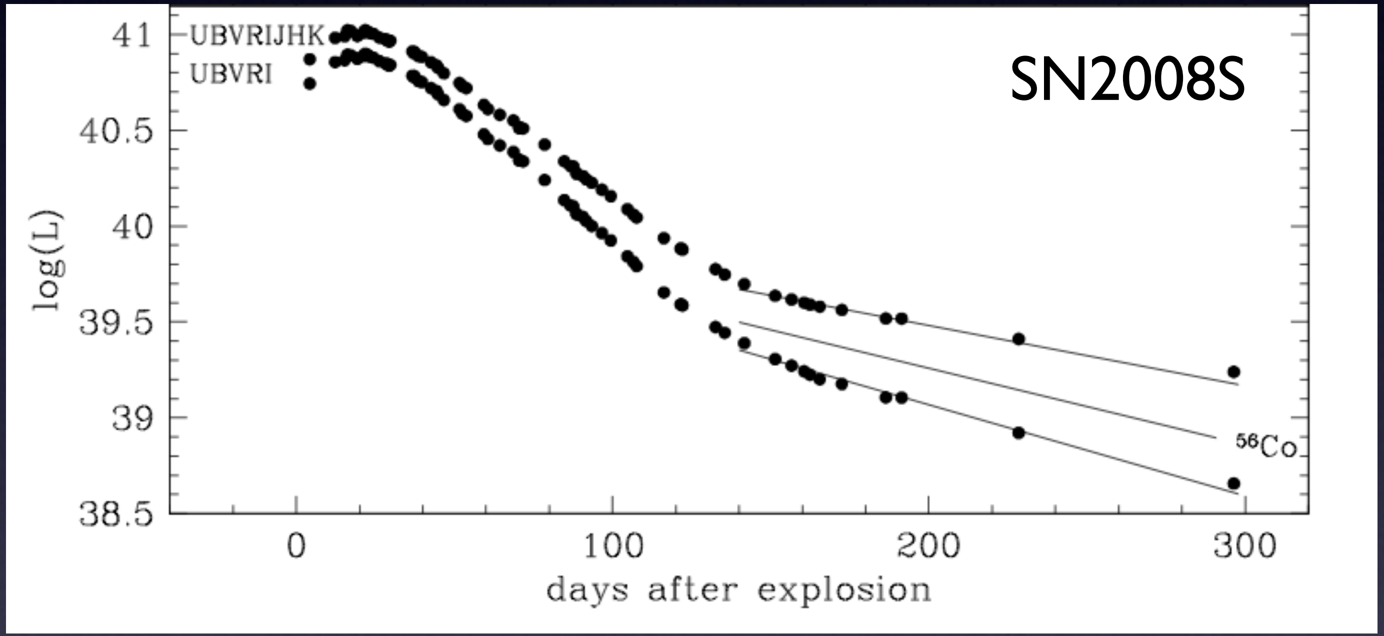
25-40 $M_\odot$ with fallback on BH

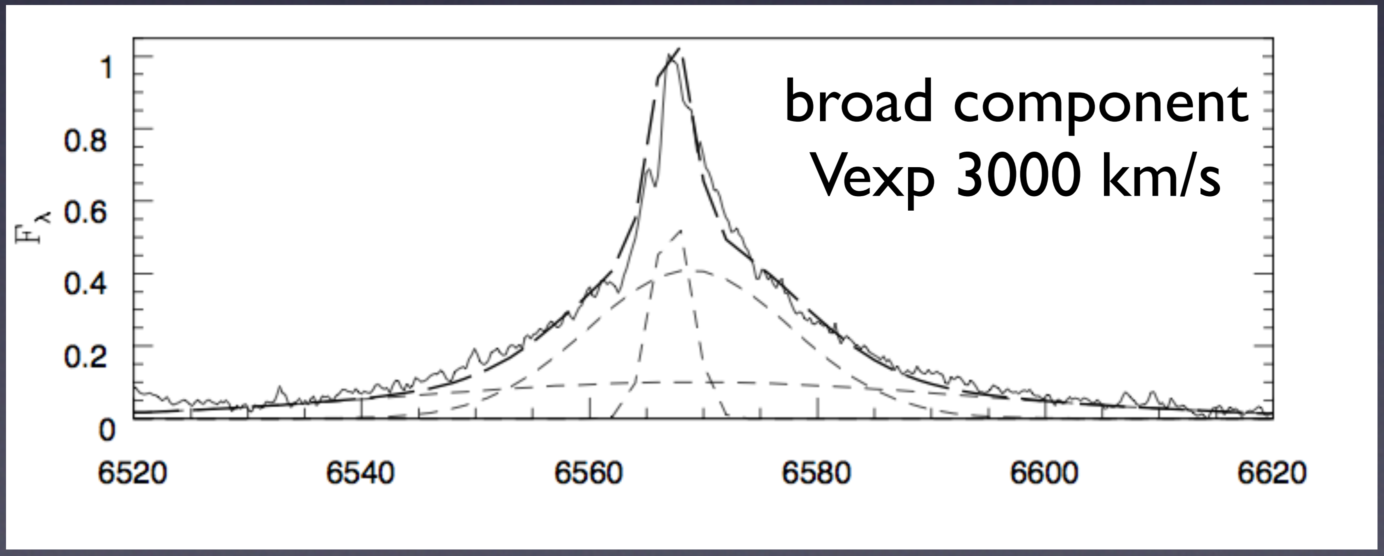
6-10 $M_\odot$ low energy CC

Outburst of massive star or ultra faint SNe ?



Botticella etal. 2009
Electron Capture in 6-8 $M_\odot$





HAWK-I Infrared SN search in a sample of starburst galaxies

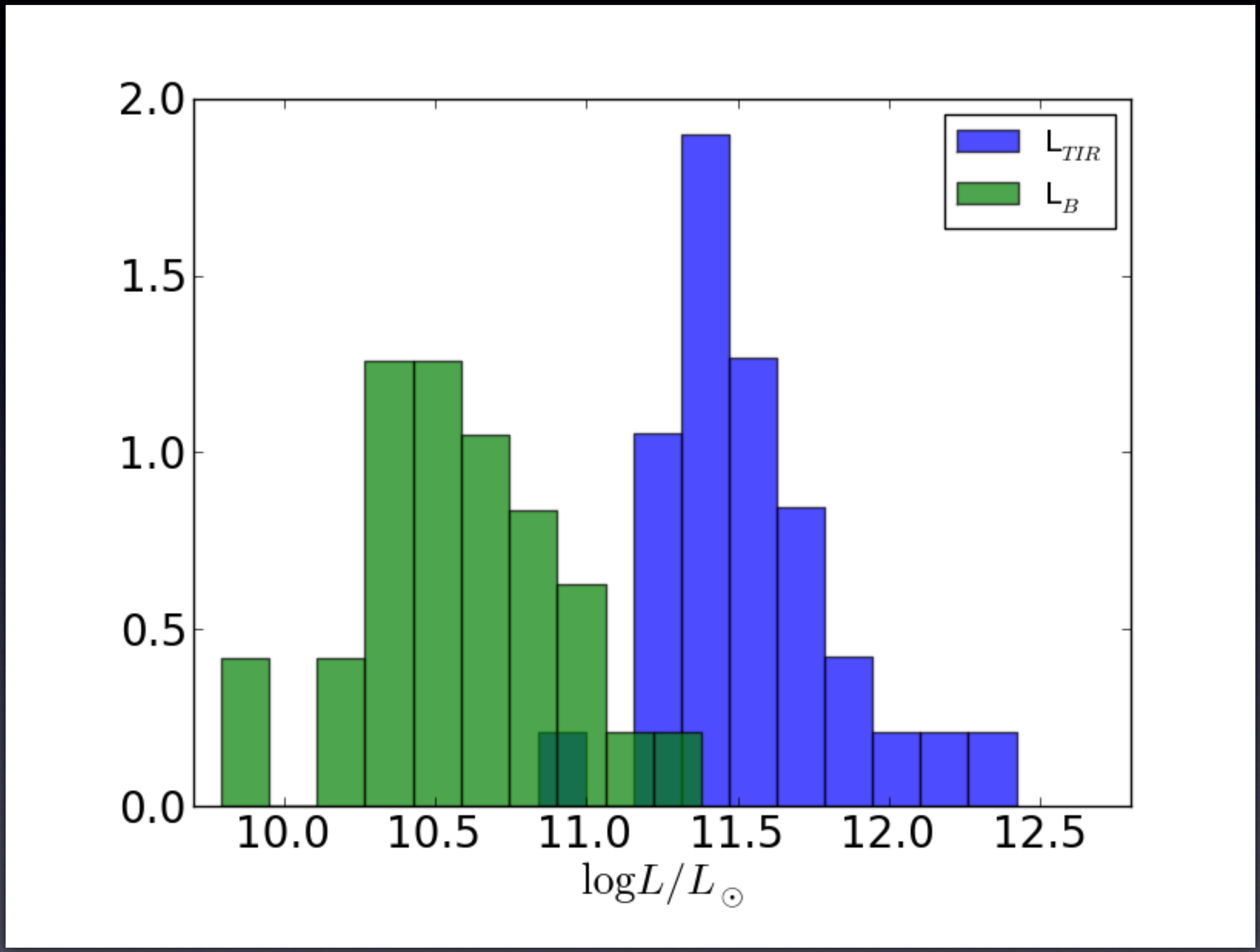
K-band VLT+HAWK-I

30 galaxies 6-10 visits 3 semesters

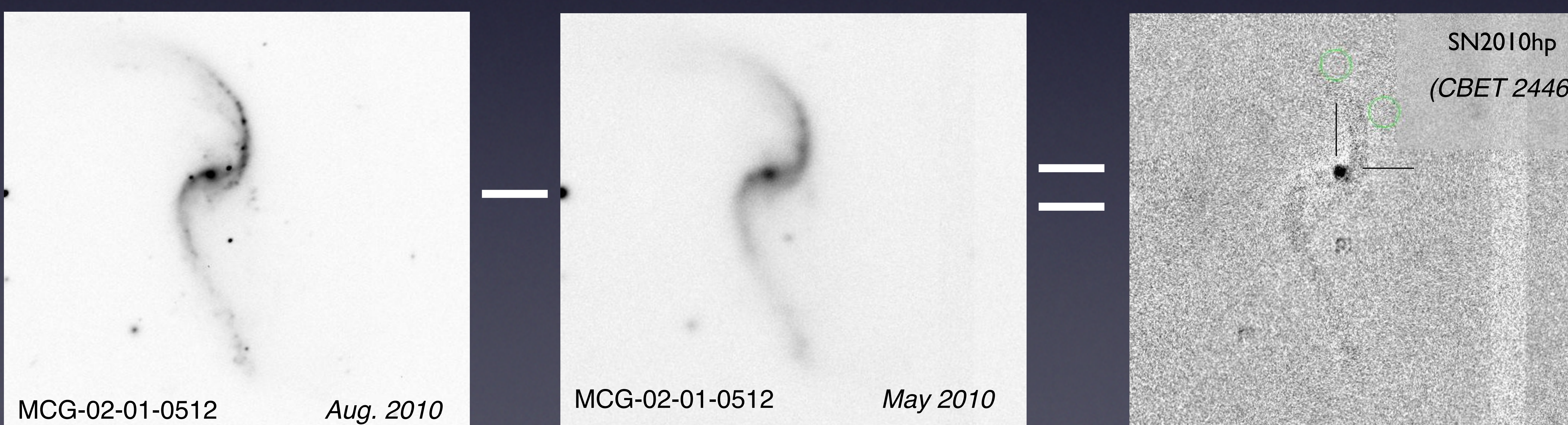
Goal: verify SN rates. Check for possible hidden population of extincted SNe

Complement Adaptive Optic search in nuclear region (cf. Kankare etal 2012)

SB galaxy sample properties

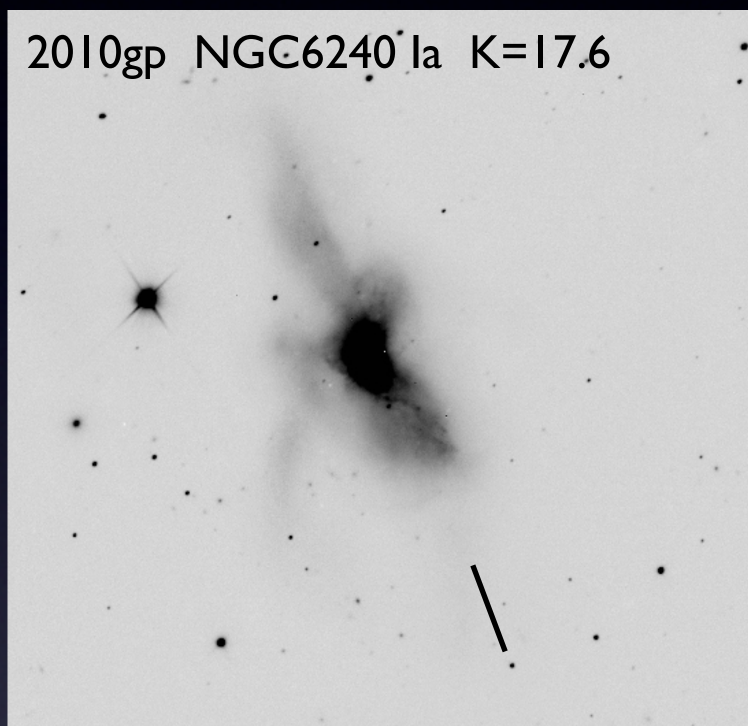


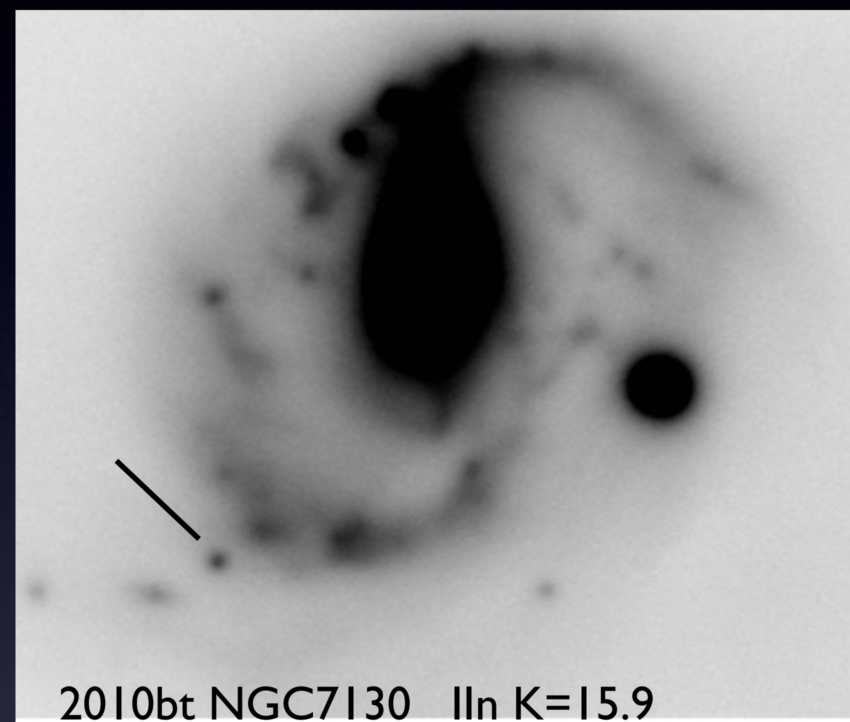
- Hawk-I pipeline: Esorex +custom programs
  - Pre-reduction
  - Build mosaic images and set astrometry
  - Image difference with PSF match (ISIS)

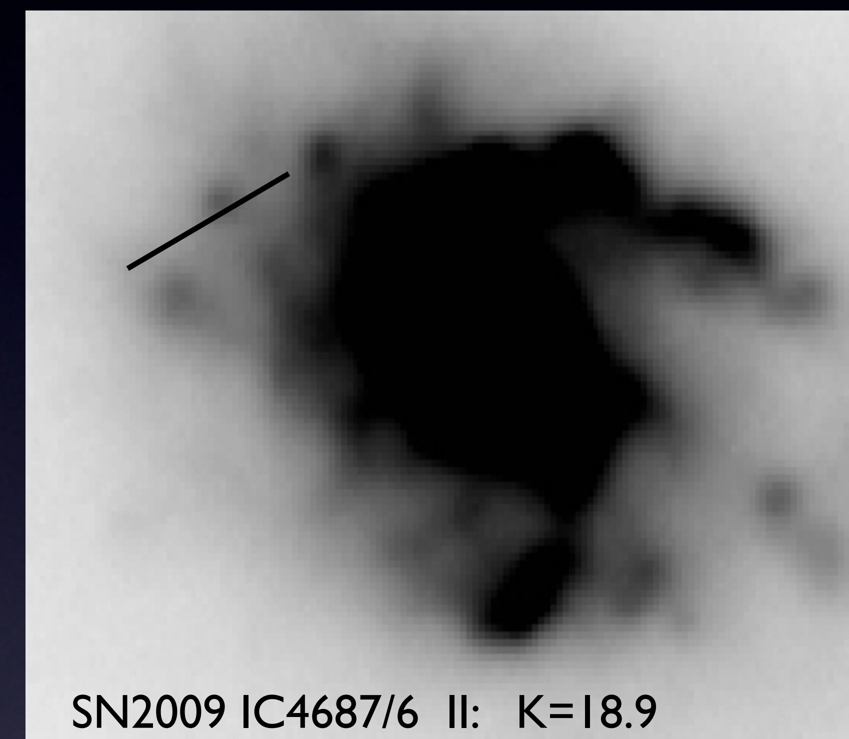


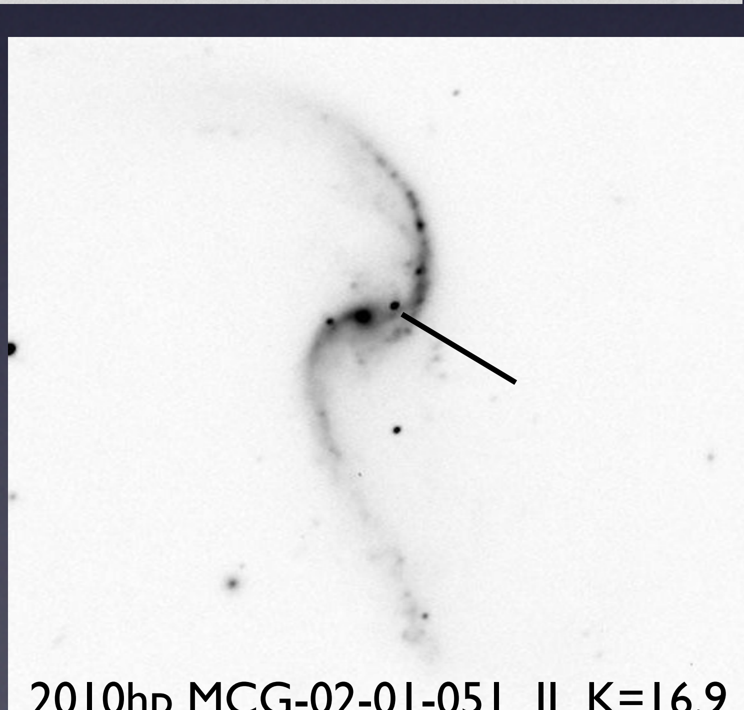
Detected SNe

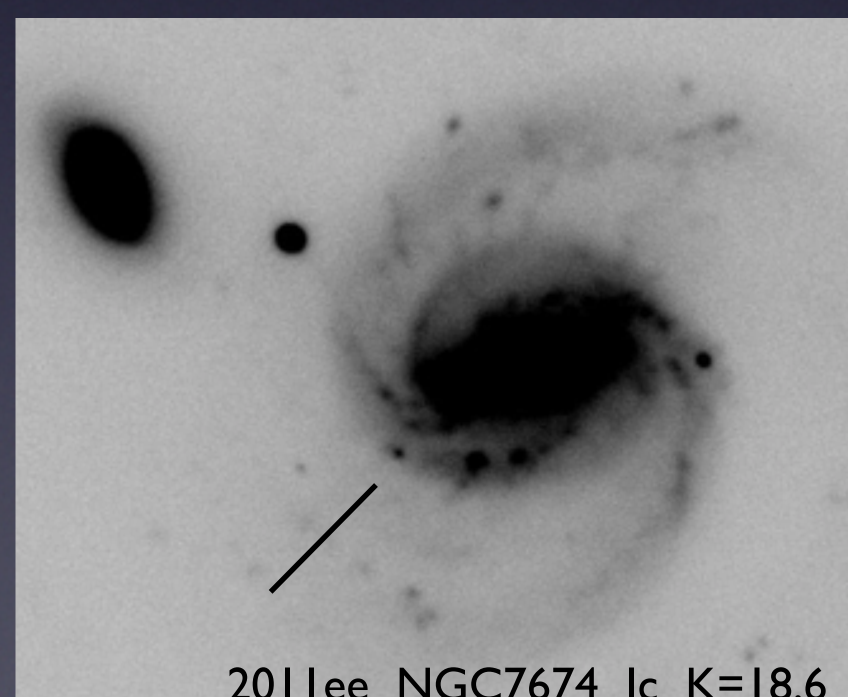
5 core collapse, 1 type Ia

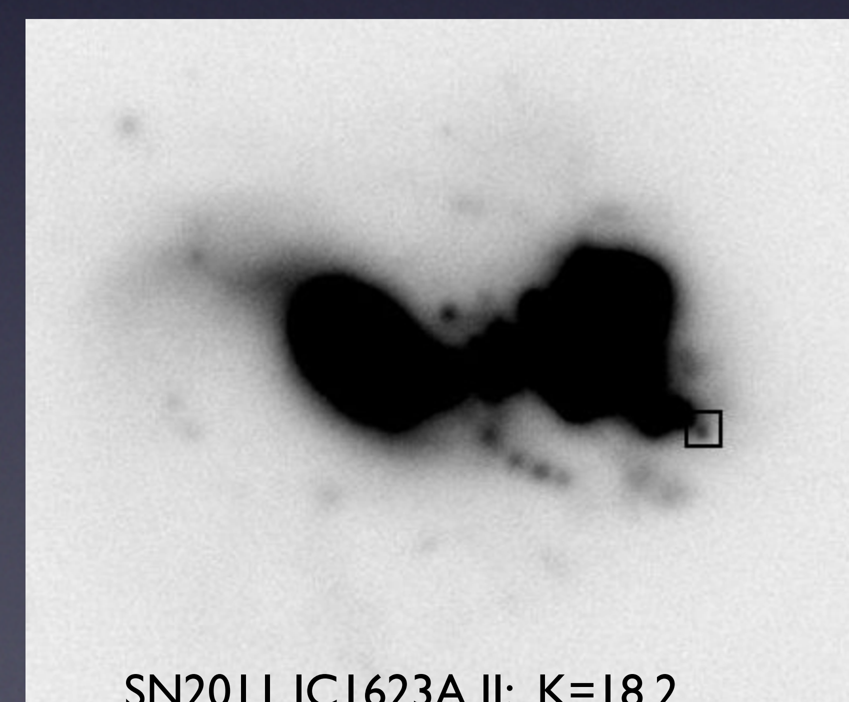






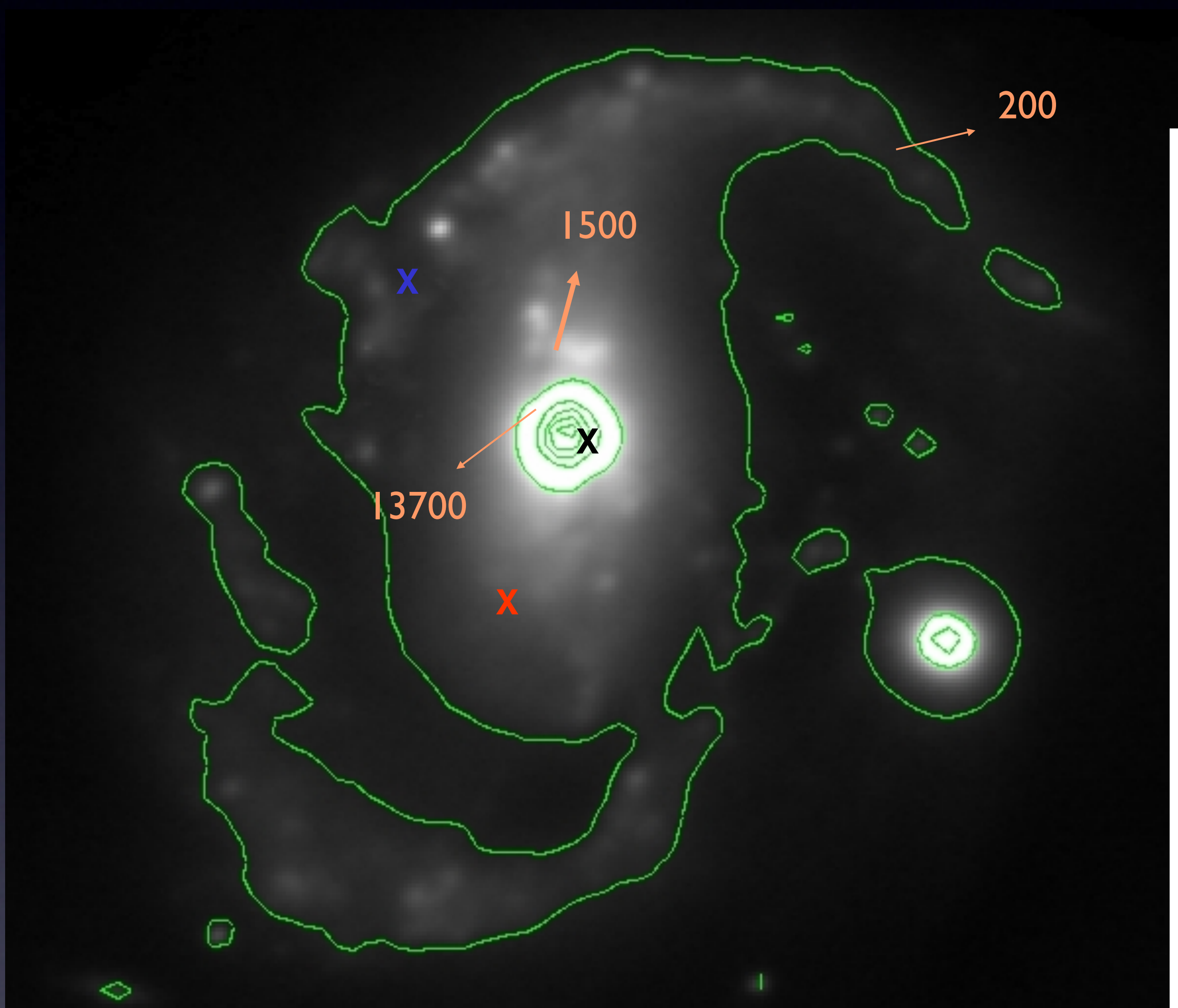


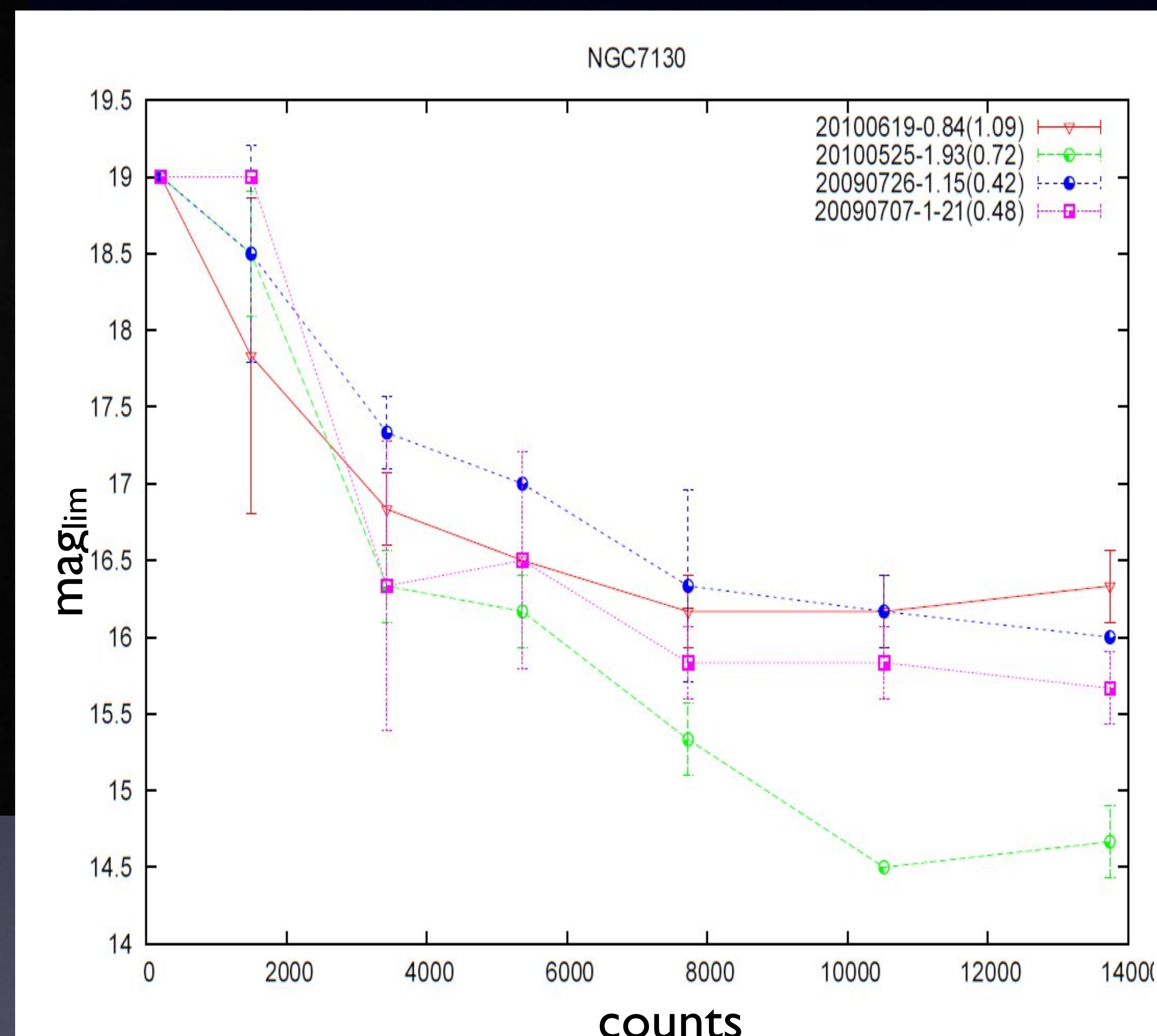




Detection efficiency

Artificial Star Experiment





Galaxies
SFR from Lum
SFR map
Extinction map

SNe
light curves
luminosity functions
K-corrections
subtype relative rates

Search
observing log
detection
efficiency map

Stellar physics
IMF
progenitor mass range

Montecarlo experiment

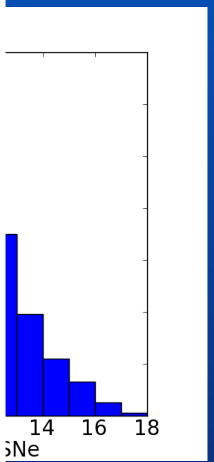
random epoch and location of explosion, absolute luminosity and extinction according to adopted distributions

Detected events

100/1000 experiments: number and properties distribution

Observed 6 (4) 5 CC / 1 Ia

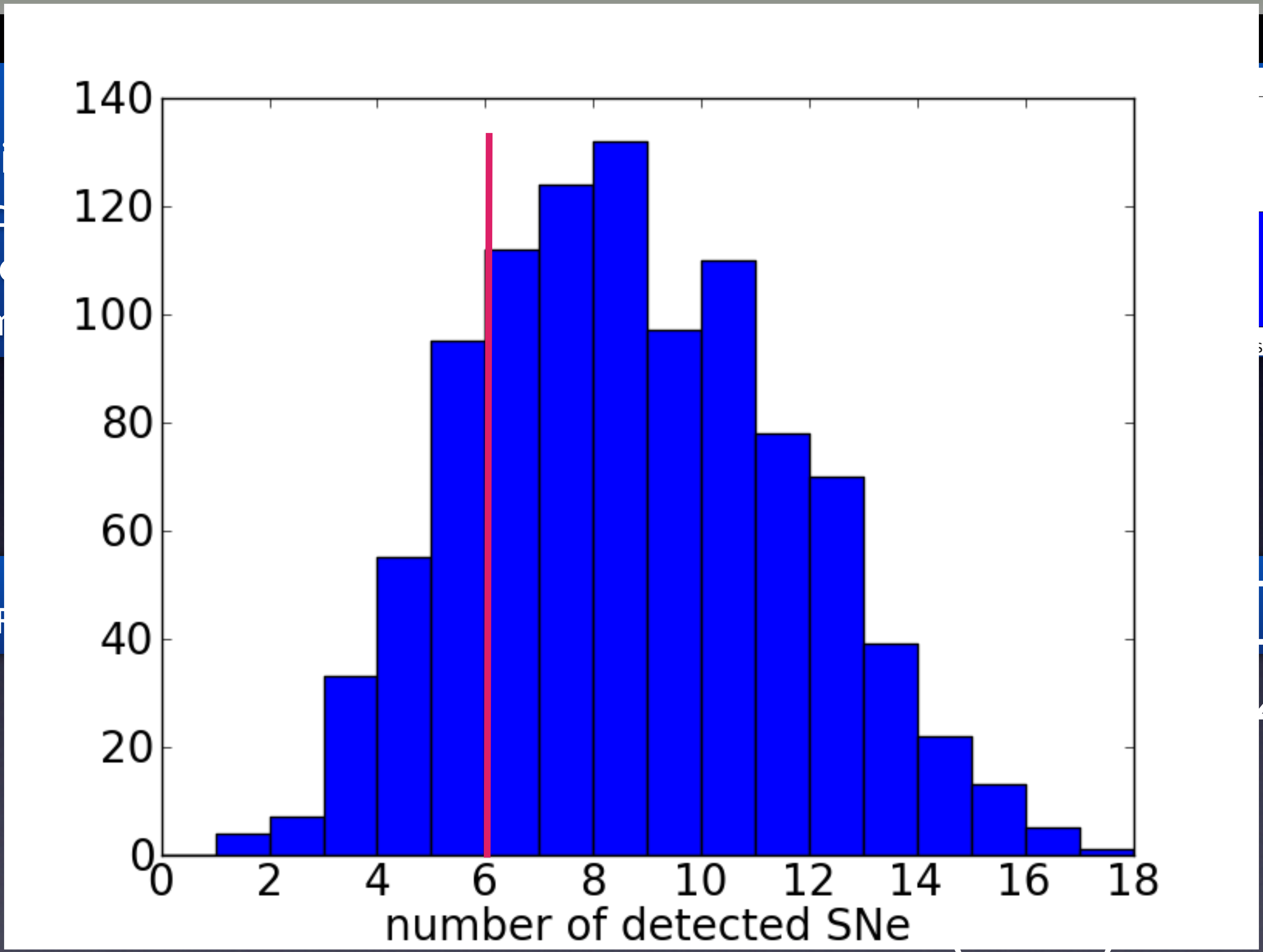
- Kenni
- SFR c
- extinc
- CC m



L_B

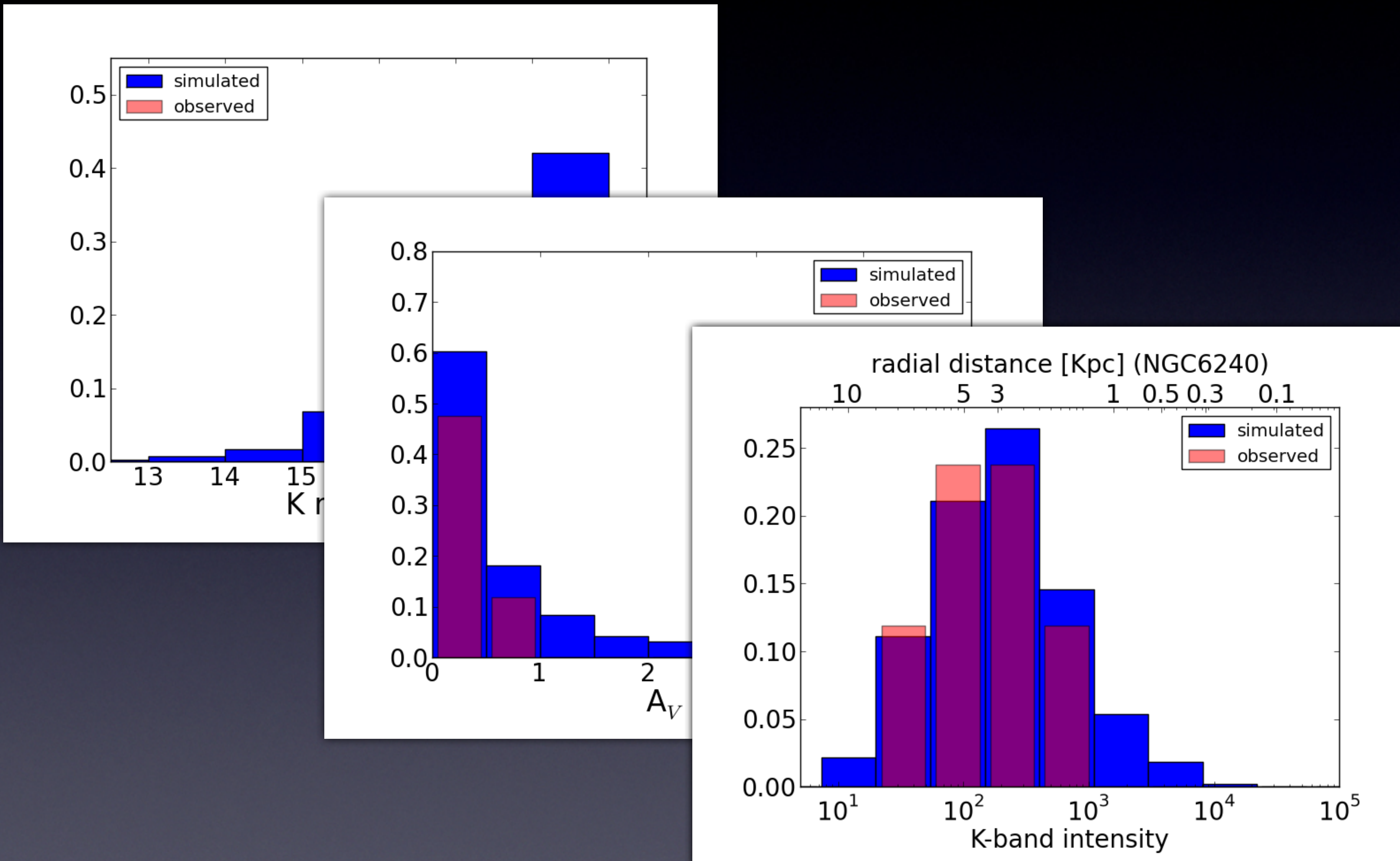
L_{TIR} [18%]

48%]



SFR $\propto L_K^{\alpha}$ α=1.5 5 ± 2 (0-10)

Test of simulation



SNe in SBs: conclusions

being written .....

- The observed rate of SNe in SB galaxies is consistent with expectations
- SF in SB galaxy is not confined to nuclear regions
- Uncertainty on SFR calibration are still large. A cross check with SN rate is definitely useful

Understand SN diversity: local sample

ESO - LP 2009 30n/yr NTT x 2.5yr PI Benetti

Public ESO Spectroscopic Survey for Transient Objects

PESSTO 2012 90n/yr NTT x 4 (5)yr PI Smartt

- Thermonuclear extremes
- Pair Instability SNe
- Ultrabright type I SNe: SNe of type I which are brighter than approximately M_{AB} -20 , and are not likely to be thermonuclear in origin
- Superluminous type II SNe: SNe of type II which are brighter than approximately M_{AB} - 20 .
- Faint core-collapse SNe: events which are possible core-collapse, fainter than M_{AB} -16 .
- SN populations in low-Z environments

PESSTO first run: this week !!!

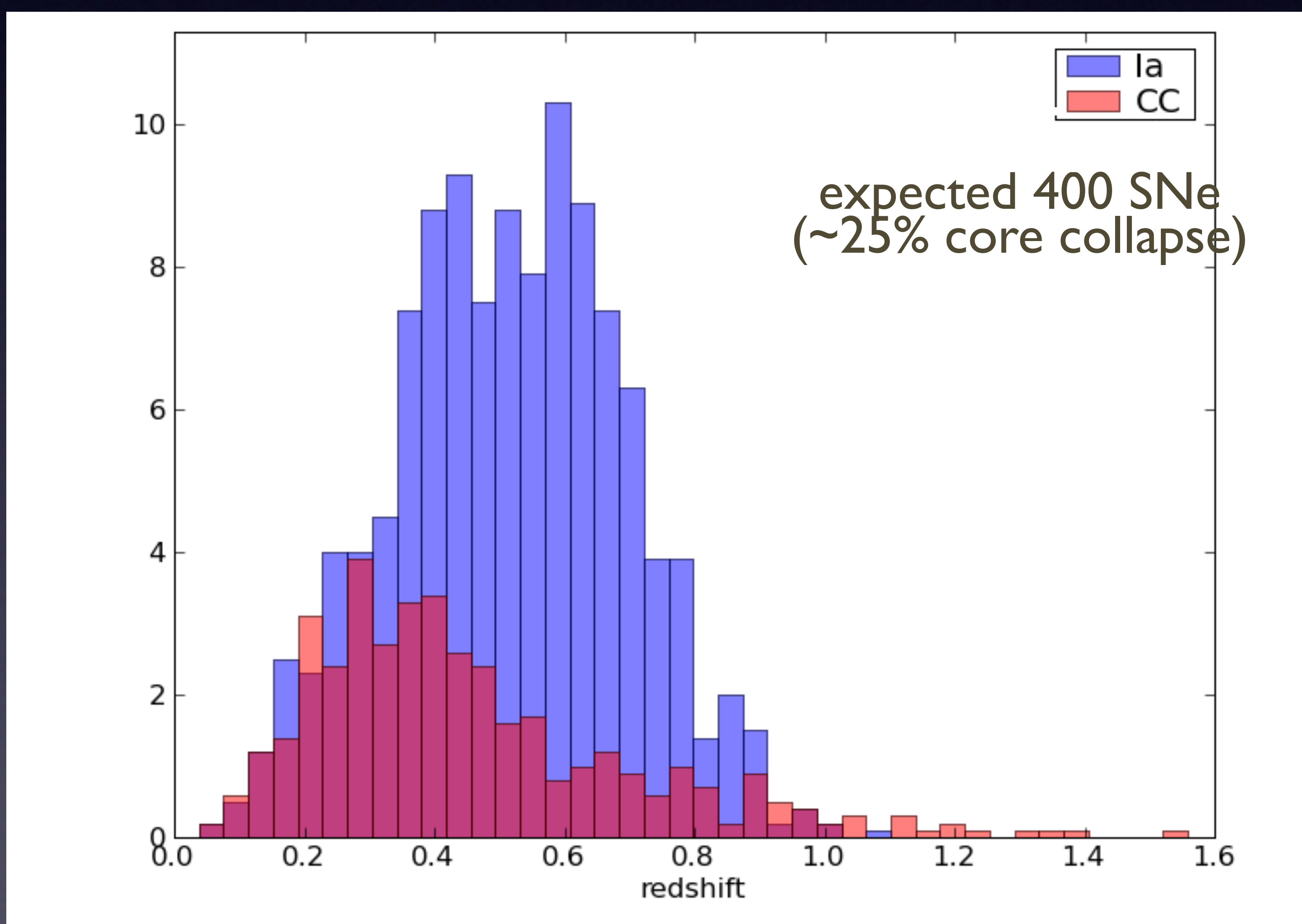
Supernova Diversity and Rate Evolution

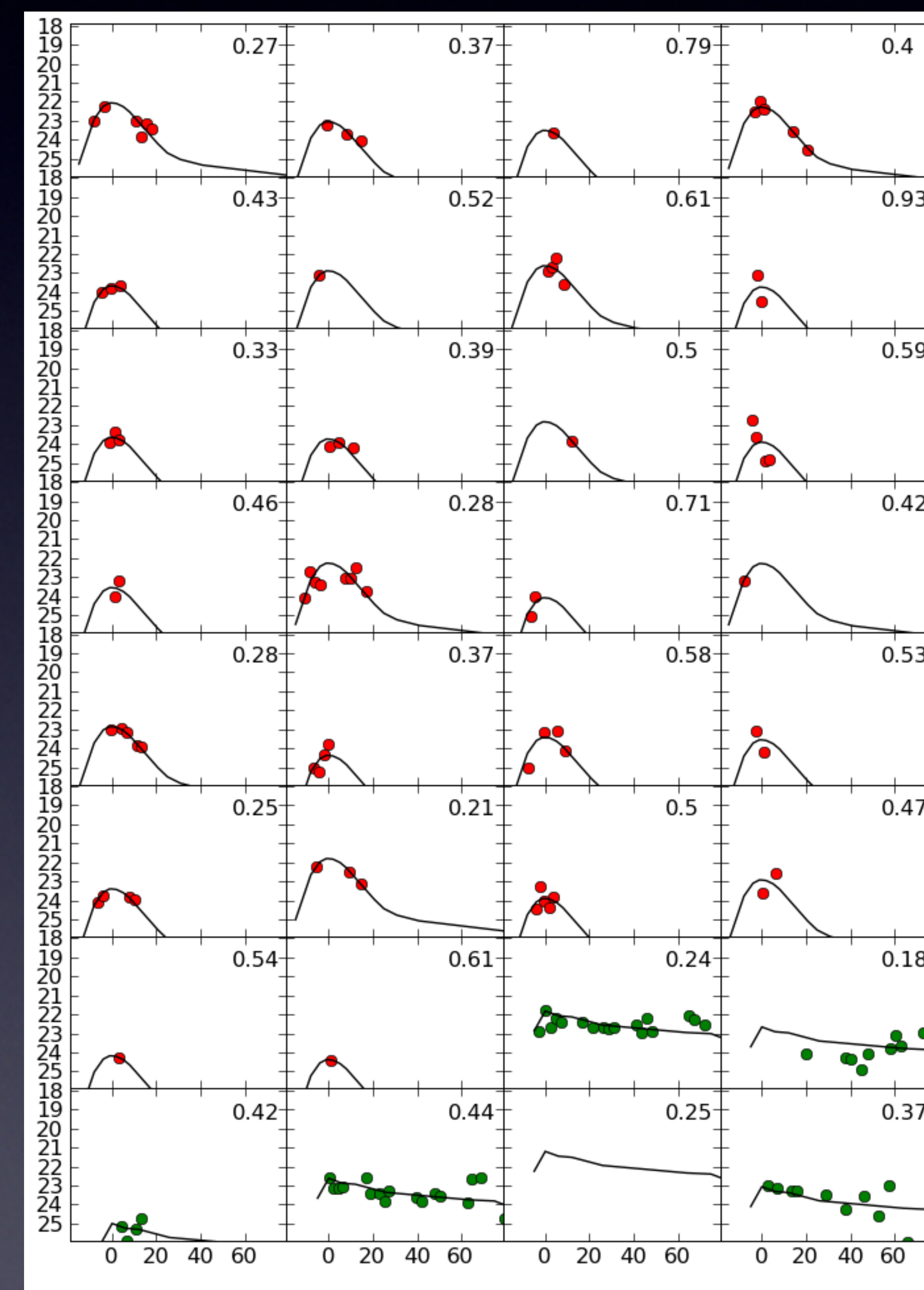
VST+ Omegacam

co-PI G. Pignata

1 □deg fields: CDFS, COSMOS

cadence: r band x3d - g i x10d
length 4yr





Observations have started ....